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Telaketju - Business from Circularity of Textiles

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RESEARCH REPORT VTT-R-00269-21

Telaketju - Business from Circularity of Textiles

Authors:	Pirjo Heikkilä, Minna Cheung, Kirsti Cura, Ilona Engblom, Jouko Heikkilä, Vafa Järnefelt, Taina Kamppuri, Minna Kulju, Inka Mäkiö, Piia Nurmi, Rosa Palmgren, Päivi Petänen, Niko Rintala, Annariina Ruokamo, Eetta Saarimäki, Kaisa Vehmas, and Marketta Virta
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Author(s) Pirjo Heikkilä, Minna Cheung, Kirsti Cura, Ilona Engblom, Jouko Heikkilä, Vafa Järnefelt, Taina Kamppuri, Minna Kulju, Inka Mäkiö, Piia Nurmi, Rosa Palmgren, Päivi Petänen, Niko Rintala, Annariina Ruokamo, Eetta Saarimäki, Kaisa Vehmas, and Marketta Virta	Pages 132
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Summary

This report is a final report of Telaketju 2 public research within a Business Finland funded project, which is the main part of the second phase of Telaketju activities. This project was composed of confidential company projects and public research. It aimed at building business from the circular economy of textiles in Finland. The scope of the project included novel circular economy business models aiming for better material efficiency and increased material and product life, and business related to textile recycling.

Research work included multiple themes within circular economy of textiles. The project group has published actively throughout the project mainly in Finnish, but also in English. In this report, we review the work and summarise results obtained within the project structures under the following themes: business models, consumers, sustainable materials, product design, recycling, and product information. It contains links to earlier and possible more detailed publications of each topic.

This report also reviews the outcome and success of the project, as we compare targets with the obtained results, and feedback collected from participating companies and other organizations. Furthermore, the Telaketju road-map has been included as part of the report focusing on the future. Dissemination activities, including links to different kinds of publications are also listed as an annex.

Confidentiality	Public

Tampere 27.8.2021

Written by	Reviewed by	Accepted by
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Preface

This is the final report of the Business from Circularity of Textiles (*Telaketju 2 BF)* project, a Co-Innovation project funded by Business Finland (BF). The Telaketju 2 BF project was a part of the larger *Telaketju* research continuum. The Telaketju 2 BF project was carried out during May 2019 - April 2021.

The project consisted of company projects and public research project. The research and development (R&D) partners of the project were VTT Technical Research Centre of Finland Ltd. (VTT, BF diary number 453/31/2019), Turku University of Applied Sciences (Turku UAS, BF diary number 826/31/2019), and LAB University of Applied Sciences (LAB, BF diary number 750/31/2019). The company partners were involved either through their own project supported by Business Finland and/or by participated funding of the public research project. The companies with their own project were Image Wear, Lounais-Suomen Jätehuolto (LSJH), Pure Waste Textiles, and Touchpoint. Companies and other organizations who participated by funding were Aijuu, Black Moda, Globe Hope, Infinited Fibre Company, Kehräämö Mustalammas, Coveross, Mirka, Nosh, Paptic, Porin Villa & Peite, Reima, Sideflow, Vaatepuu, Valmet, Freudenberg, Fida, Nextiili, Painovoima, Helsinki Metropolitan Area Reuse Centre, Saimaan Virta, Verstas 247 and Finnish Textile and Fashion.

The Telaketju BF 2 project was coordinated by VTT. The project manager was Pirjo Heikkilä (WP1 & WP8 leader), and the responsible leaders were Jani Lehto and Katariina Torvinen. The VTT key personnel also included Ali Harlin, Taina Kamppuri (WP4 leader), Eetta Saarimäki (WP6 leader), Kaisa Vehmas, Minna Kulju, Maria Antikainen, Vafa Järnefelt, Ville Hinkka and Jouko Heikkilä. The project managers at Turku University of Applied Sciences were Henna Knuutila (WP2 leader) and Piia Nurmi, and key personnel included Marketta Virta (WP7 leader), Inka Mäkiö (WP5 leader) and Ilona Engblom. The project manager at LAB University of Applied Sciences was Kirsti Cura (WP3 leader), and the key personnel included Niko Rintala, Minna Cheung and Annariina Ruokamo. A large group of other researchers as well as technical staff, also participated in the project work.

The authors would also like to acknowledge the students from Turku UAS and LAB who participated in the research work including, for example, Minna Ainonen, Aleksi Leppänen, Kaisa Ahonen, Enni Arvez, Sofia Malin, Mirka Uunimäki, Veera Konga, Henna Ahola, Veera Laaksonen, Hanna Vuorela, Beda Suni, Nelli Löfberg, Joona K. Ikonen, Elina Lundén, Raisa Airola, Sonja Salminen, Emmi Loijas, and Anne-Mari Savola.

The results of the Telaketju 2 BF project are presented is this report. Many parts of the work have been published as separate reports or publications. In such cases, mainly summaries and/or conclusions with links to other publications are included here.

Tampere 24.8.2021

Authors

Contents

Abbreviations

AI	artificial intelligence
CaaS	clothes as a service - a business model
CD	cyclodextrin
CO	cotton
CV	viscose
DSC	differential scanning calorimetry
EA	elastane
EC	European Commission
EPR	extended producer responsibility
ERDF	European Regional Development Fund
EU	European Union
GDPR	general data protection regulation
IFC	Infinited Fibre Company
LAB	LAB University of Applied Sciences
LCA	life cycle analysis
LSJH	Lounais-Suomen Jätehuolto Oy
MODIX	modular mixed cylindrical extruded technology developed by VTT
NIR	near infra red
NIRS	near infra red spectroscopy
PA	polyamide
PEF	product environmental footprint
PES	polyester
PET	polyethylene terephthalate, polyester type
PLA	polylactide, bio-polyester
PHA	polyhydroxyalkanoate
PP	polypropylene
PUR	polyurethane
R&D	research and development
R-CO	recycled cotton
R-PET	recycled polyester
REACH	registration, evaluation, authorization and restriction of chemicals
RFID	radio frequency identification
SCBA	social cost benefit analysis
SD	system dynamic (modelling)
SME	small and medium sized enterprise
STJM	Finnish Textile & Fashion
SYKE	Finnish Environment Institute
TEM	Ministry of Economic Affairs and Employment
TPE	thermoplastic elastomer
Turku UAS	Turku University of Applied Sciences
UV	ultraviolet (radiation)
VAT	value added tax
WO	wool
WP	a work package of the project (WP1−WP8)

1 Introduction

This first part of the report includes a short introduction to the circularity of textiles (Chapter 1.1), it describes the Telaketju research and the current project (Chapter 1.2) and gives an introduction to our consortium including some survey results of how our partners see their role in the textile circular economy (Chapter 1.3).

1.1 Circularity of Textiles

Circular economy (or circularity) is an extensive concept, which has various definitions. In the EU's General Union Environment Action Programme to 2020 (EU, 2013) the vision for 2050 describes circular economy as "*where nothing is wasted and where natural resources are managed sustainably, and biodiversity is protected, valued and restored in ways that enhance our society's resilience*". Geissdoerfer *et al.* (2017) have thoroughly examined different definitions of the concept and concluded with the definition: "*a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling*". Ellen MacArthur Foundation (2017a) defines that "*in a circular economy, economic activity builds and rebuilds overall system health*". They include three principles: design out waste and pollution; keep products and materials in use; and regenerate natural systems. Circular economy has been introduced as a sustainable alternative to the linear economy where the products are thrown away as a waste after their use.

In a circular economy we can expect products to have multiple cycles as products, and also material cycles when products are no longer suitable for use. Different circular economy strategies and activities ensure that products and materials are kept in use for as long and as effectively as possible. The main strategies are presented in Table 1. All of these strategies from circular design to new service based models for use, share and re-use, as well as recycling, are applicable to textile products.

Table 1 Main strategies of circular economy (Geissdoerfer et al.*, 2017; Ellen MacArthur Foundation 2017b)*

Strategy / Activity	Description
Long-lasting design	Product is designed and produced as such that it can and will be kept in use for long
Share	The use of the product is shared between multiple users
Maintain / Repair	Product maintained and repaired to be kept in use
Reuse	Disused product will be transferred to a new user
Refurbish / Remanufacture	Restore an old product. It may also be updated. Remanufactured products are sold (as good as) new products
Recycle	Process materials for use as raw materials in new products at the end of the life of an old product

An illustration of a circular textile ecosystem is shown in Figure 1. Activities and therefore, also needs to gathering information about products are more complex and more crucial to business compared to the linear economy. The development of information sharing and communication technologies may play a significant role in circular economy in the managing of supply chains and product life cycles (Jia *et al.*, 2020).

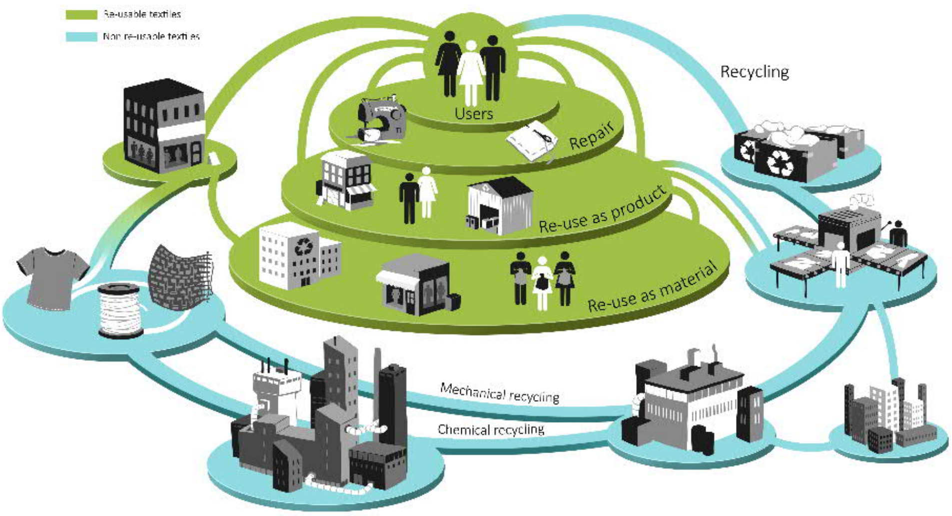

Figure 1 Model of circular economy of textile including products (green) and material cycles (blue). (Fontell & Heikkilä, 2017)

1.2 Telaketju Research

The Telaketju activities can be seen as a research continuum where all Telaketju projects, as well as other related research activities, have been networking and co-operating. It involves building a new kind of multi-stakeholder business ecosystem around textile recycling. This helped the organisations involved in and/or linked to the Telaketju ecosystem and the Finnish society to transfer from the linear production and use of textiles towards more circular system.

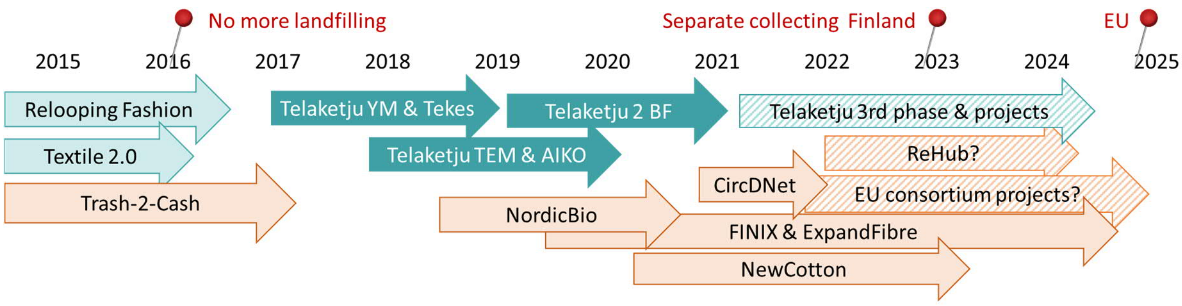

Figure 2 Telaketju research continuum. Turquoise colour indicates predecessor projects and projects, namely involved in Telaketju. Other projects involve Telaketju partners as partners. More info[1]

In the first phase in 2017-2018, the common target of the Telaketju network and activities was a better utilization of textile waste in Finland, see Figure 3. This was carried out by launching simultaneous actions and R&D projects in textile collection and sorting, as well as in processing and product development. The first phase Telaketju included two cooperating projects that had common tasks and linkages, namely the Telaketju YM project and the Telaketju Tekes project. The main funding bodies of these were The Ministry of Environment and Tekes/Business Finland, respectively. In 2018, two new projects funded by The Ministry of Employment and the Economy (TEM project) and Regional Council of Southwest Finland (AIKO project) were started. These projects focused on the development of a refinery plant of end-of-life-textiles by Lounais-Suomen Jätehuolto (LSJH).

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[1] www.telaketju.fi; https://cris.vtt.fi/en/publications/the-relooping-fashion-initiative; https://www.trash2cashproject.eu/; https://cris.vtt.fi/en/publications/nonwovens-from-mechanically-recycled-fibres-for-medical-applicati; https://finix.aalto.fi/; https://www.expandfibre.com/; https://circinnovation.com/; https://newcottonproject.eu

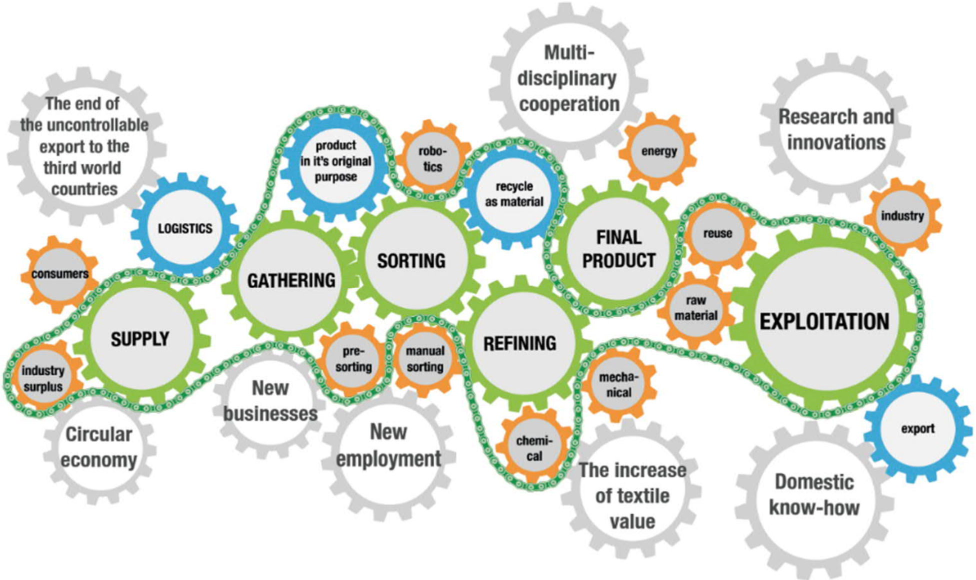

Figure 3 A circular textile ecosystem: the main activities, requirements and effects

Second phase funding from Business Finland, i.e. this Telaketju 2 project, was applied after the end of YM and Tekes projects. Then the focus moved from recycling to circular economy business models. The public research project was planned to help the companies to reach those goals by providing them with better readiness for the transformation from a linear to a circular economy. The public R&D project partners were VTT Technical Research Centre of Finland Ltd. (VTT), Turku University of Applied Sciences (Turku UAS) and LAB University of Applied Sciences (LAB). The consortium, including companies that participated in the project, is introduced in Chapter 1.3.

The public part of the Telaketju 2 BF project was composed of eight work packages (WPs), which are illustrated in Figure 4. We aimed to build and strengthen the circular ecosystem of textiles by networking both nationally and internationally (WP1).

Novel circular business models were studied and developed, and companies were provided with tools communicating about circular solutions within their value chain (WP2). We reviewed the effect of product design on material and a product’s life span and recyclability, integrated product information in the circular economy, as well as bio-based solutions for textiles (WP3).

We developed a concept for textile collecting and pre-sorting, textile identifying and sorting systems, and generated a model for classification the of recycled textile materials (WP4). Environmental, social and economical sustainability were studied (WP5). Participants of the project represent various stakeholders in circular economy, which enables us to make fast experiments with novel business models, as well as demonstrate processes and products, thus, modelling future recycling value chains (WP6).

Consumers needs to be involved in the circular economy of textiles and, therefore, we studied consumer attitudes towards circular products and business models, and directed our communication activities also to the common public (WP7). We aimed also to increase business opportunities by supporting ecosystem building, and reviewed scalability and export the potential of results, as well as further development and research needs (WP8).

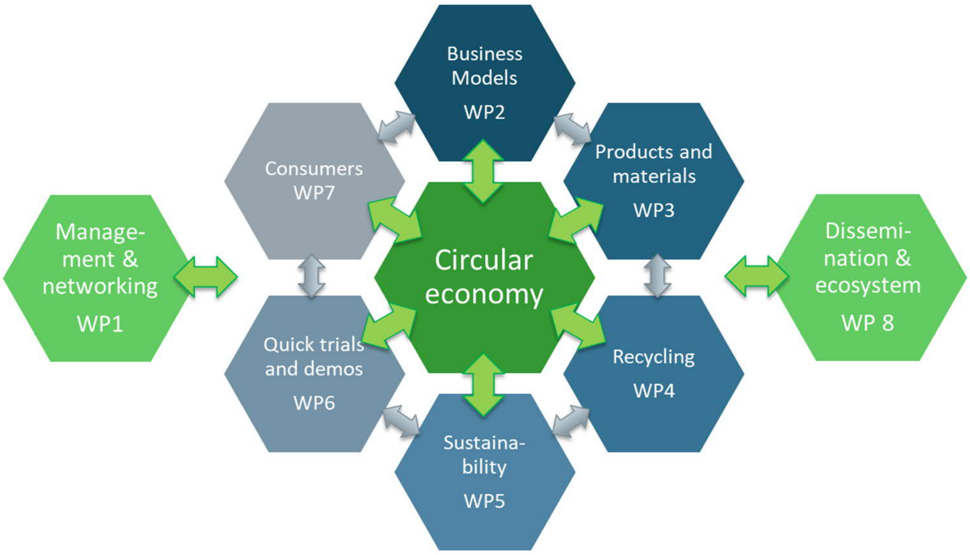

Figure 4 Work package structure of Telaketju 2 BF project

This report summarised research results carried out within these WP's organized under the following themes: sustainable business models in Chapter 2, consumer attitudes in Chapter 3, sustainable materials in Chapter 4, circular products in Chapter 5, recycling in Chapter 6 and product information in Chapter 7. Chapter 8 gives an overview of the outcome of the project, also including feedback from the consortium and a road-map for the future. Dissemination activities are summarized as an Annex of the report.

1.3 Telaketju Consortium

Telaketju consortium included 28 partners representing research and academia, companies, non-profit organizations and associations (see Figure 5).

Figure 5 Telaketju 2 BF project consortium

Research partners:

- VTT - Technical Research Centre of Finland Ltd is a state owned non-profit multi-technological company focusing on applied research (https://www.vttresearch.com/en). A coordinator and research partner of Telaketju, who provided expertise e.g. on business model development, product data studies, economic modelling, recycling technologies and demonstration, consumer studies, and road-map work.
- Turku University of Applied Sciences (Turku UAS) is a multidisciplinary educational community of around 9000 students and 700 experts (www.tuas.fi). Turku UAS is located in Southwest Finland, but nowadays it operates globally in various development activities. Circular economy is in Turku UAS strategy, namely “growth from circular economy”. Turku UAS has a research group which focuses on research and development of circular economy. The name of this group is *Circular Business Models*. This research group is one of the largest research groups from the over 20 existing research groups at Turku UAS. Turku UAS is a member of the Ellen MacArthur Foundation.
- LAB University of Applied Sciences (LAB) is a higher education institution focusing on innovation, business and industry, located in Lahti and Lappeenranta (www.lab.fi). LAB has 8500 students and 360 staff members, making it the sixth largest university of applied sciences in Finland. LAB’s specialities in the field of RDI are circular economy, design, the commercialisation of innovations, and service innovations for health and well-being. The research activities aim at finding, developing and producing new and improved products, production systems, methods and services. In Telaketju 2, LAB’s activities involved textile identification development, using NIR and circular product design. LAB is a member of Ellen MacArthur Foundation and Netfas network (netfas.eu).

Companies and their business areas and/or role in the project:

- Aijuu - Entrepreneurship educator, provider of consulting services
- Black Moda Oy is a well-established family owned textile company in Finland. Owned by the same family, Black Moda Portugal is an OEKO-TEX® certified sewing company, located in Ponte de Lima, specialized in cutting and sewing casual tricot clothing. Its goal is to improve more circular economy and responsible textile production. The company provides production to B2B customers, who are mainly Finnish textile brands (https://blackmoda.fi/en/references/). In addition to jerseys and fabrics, our range includes terry towels and bathrobes, socks, knitwear, and home and kitchen linen. These are manufactured by long-term and reliable partners in Portugal and Italy. Black Moda Oy is responsible for the marketing and production of RATIA textile products, and has two of its own brands: Puuvillatehdas and PikkuSet. The brands also include the Aarrelabel brand, owned by the siblings of the owner family
- Globe Hope - Manufactures clothes, accessories and BtoB-products out of recycled and left-over materials, since 2003. Globe Hope also provides a service for companies to recycle their textile waste. Globe Hope’s mission is to increase textile materials recycling and save planet precious resources. Learn more on https://globehope.com/
- Image Wear - The leading work wear manufacturer and distributor in Finland. We produce work wear for health care, service and industrial sectors. Sustainability is at the core of our strategy
- Infinited Fiber Company (IFC) was born out of the desire to solve some of the biggest challenges in the textile industry – mountains of waste, limited natural resources, and consumers calling for more sustainable choices. IFC’s technology enables circular fashion cycle since it can also use mixed cellulose based waste and its own regenerated fibre as feedstock over and over again
- Kehräämö Mustalammas - *‘The Blacksheep woollen mill’* processes Finnish lamb’s wool to feltingwool, fillingwool, curewool, prefelt and felted accessories. Bought straight from Finnish

sheep farms, the wool is washed and dyed at the Blacksheep woollen mill. The owner of the woollen mill is Piritta Mäkinen Oy

- Coveross develops functional garment and textile solutions for brands, retail, and work wear. We can process fabric made from most natural fibres and man-made fibres, and their blends. We can also make functional finishing for recycled materials. Coveross functional finishing can be applied to fabrics, and ready-made garments and textile products
- Lounais-Suomen Jätehuolto (LSJH) is a municipal waste management company. LSJH guides people in living more sustainably and organize waste reception services for households and public services. LSJH utilizes up to 98 % of the received waste as material and energy. LSJH is a company owned by 17 municipalities. On behalf of these municipalities, LSJH takes care of organising the residents' waste management and waste disposal advice with almost 100 employees. LSJH is active actor in the circular economy field and has led many projects related to the circularity of textiles, waste to energy solutions and developing old landfill areas towards circular economy centres. LSJH has been one of the co-coordinators in the Telaketju network
- Mirka is a family-owned company, with about 800 employees in Finland, and a total of 1400 worldwide. We produce sanding solutions for the surface finishing and precision industry, and some of our flexible abrasive products are textile based. Our role in Telaketju has been to find out if anyone can use our textile waste, or if we could return it back to our own production
- NOSH is a Finnish sustainable clothing brand. We offer a selection of high quality clothing for women, men and kids. Visit our Finnish webshop: www.nosh.fi
- Paptic - Producer of packaging materials
- Villa & Peite - Producer of futons, blankets and pillows from natural materials
- Pure Waste is a Finnish company breaking new ground in textile recycling – we manufacture and sell yarns, fabrics, and garments made from 100% recycled materials. Our mission is to create recycled products that inspire change towards a world without textile waste. Therefore we are committed to using recycled materials. Pure Waste products are available for both consumers and corporate customers – we are happy to help on the path towards a more sustainable lifestyle. For more information visit our website www.purewaste.com
- Reima is a globally leading brand in kids' active wear. It is known for its award-winning innovation and high-quality clothing. Reima offers a 'tip-to-toe', year-around collection for active kids aged 0 to 12 years. In addition to outdoor and innerwear clothing, the offering includes a wide range of accessories, footwear as well as solutions and services for kids. Reima's products are available in over 70 countries across the world
- Sideflow - A marketplace for rescue materials from textile productions. Sideflow is specialized in reducing textile waste through procuring pure material side streams and deadstock from textile industry. Sideflow supports waste-free fashion through a production and design consultancy and sideflow.fi -marketplace, where textile manufacturers can source the most ecological materials in the market - rescue textiles
- Touchpoint is a fore runner as a sustainable work wear producer. We are a part of a bigger eco system in the textile industry aiming towards circular economy. Together with our partners we develop new business models, ecological work wear solutions and closed loop solutions for end-of-life textiles
- Vaatepuu - Clothing library services for consumers
- Valmet is an established market leader and has a strong market position in all its businesses. The services business line provides customers with mill improvements, roll and workshop services, spare parts, fabrics, and life-cycle services. Valmet's Fabrics Business Unit is a full line clothing supplier offering fabric solutions for the entire paper, board and tissue machines. Our filter fabrics serve the pulp and paper, mining and chemical industries in various processes

- Vileda Professional/Freudenberg Home and Cleaning Solutions Oy - Production and sales of professional mechanical cleaning tools

Other organizations:

- Fida second-hand is the one of the largest chains of charity second-hand stores in Finland, with over 40 years' experience in textile collection and sorting. Each year, approximately 1.5 million kilos of donated textiles are recycled and exchanged into a better life for the world's poorest children by us. We aim to bring hope and a future to the poorest of the poor
- Nextiili-paja - The meaning of the organization is to improve the framework of circular economy and support common wellbeing and strengthen participation. To progress circular economy know-how, we act as a learning environment and information distributor. With working methods we advance trainees' control of life and working and studying completeness and support development of skills and know-how. In collaboration with learning institutions young and adults have a possibility to collect information and abilities and social funds that they can head towards working life and social strengthening. To execute their meaning, the organization can arrange the possibility to working trials and employ a salary support period for those who have been looking for jobs for a long time. Additionally, the organization arranges education in collaboration with local trade schools, execute development projects related to circular economy and carrying out influence work
- Painovoima - Association/workshop using textile waste in papermaking
- Pääkaupunkiseudun Kierrätyskeskus - Helsinki Metropolitan Area Reuse Centre
- Saimaan Virta - The association and social employer in South-East Finland. We enhance unemployed people to get work by training and improving working skills. Sustainability and textile recycling are in an important role in our business. We collect, recycle and find new uses for textile waste
- Suomen Tekstiili & Muoti - Finnish Textile and Fashion (STJM) is the central organization for textile, clothing and fashion companies in Finland. Member companies produce, for example, clothing, home textiles, sportswear and outdoor apparel. They also manufacture industrial nonwovens as well as technical industrial textiles. STJM is a significant industry influencer, and its goal is to ensure that Finnish textile companies have a beneficial business environment that meets their changing needs. STJM's aim is also to provide the companies with good opportunities to grow, internationalize and succeed. Circular economy has been one of STJM's focus areas and STJM participated in Telaketju, because they see in circularity a lot of great business opportunities for Finnish companies
- Verstas 247 - Open workshop for handicrafts

Every partners' business model and strategies were somehow linked to circular economy. Circular economy is an economic model where more items are not produced continuously, but consumption is rather based on products as a service, and sharing, renting and recycling instead of ownership. There are still many challenges in implementing circular business models. The most crucial one is to establish a profitable business. Other obstacles are people's attitudes, missing value chains of textiles and the high cost of end-of-life textile processing, for example. The development of circular economy business models is still in its early stages and the treatment and recycling processes for end-of-life textiles still need to advance.

Telaketju consortium partners viewed their current business models and how they would like to develop them by the year 2025, see Figure 6. Regarding the traditional manufacturing and selling model, there will be no apparent change by the year 2025. In the other models there would be more changes happening by 2025, mostly improvements. The circular business models, product-as-a-service, sharing economy and recycling, were seen to grow significantly in the future. To meet these goals, most of the partners thought that textile materials need to change, technology needs new innovations and business models need to change. A minor part of the partners also needed a change in consumers' attitudes, openness, funding, partnership or utilization of recycled fibres.

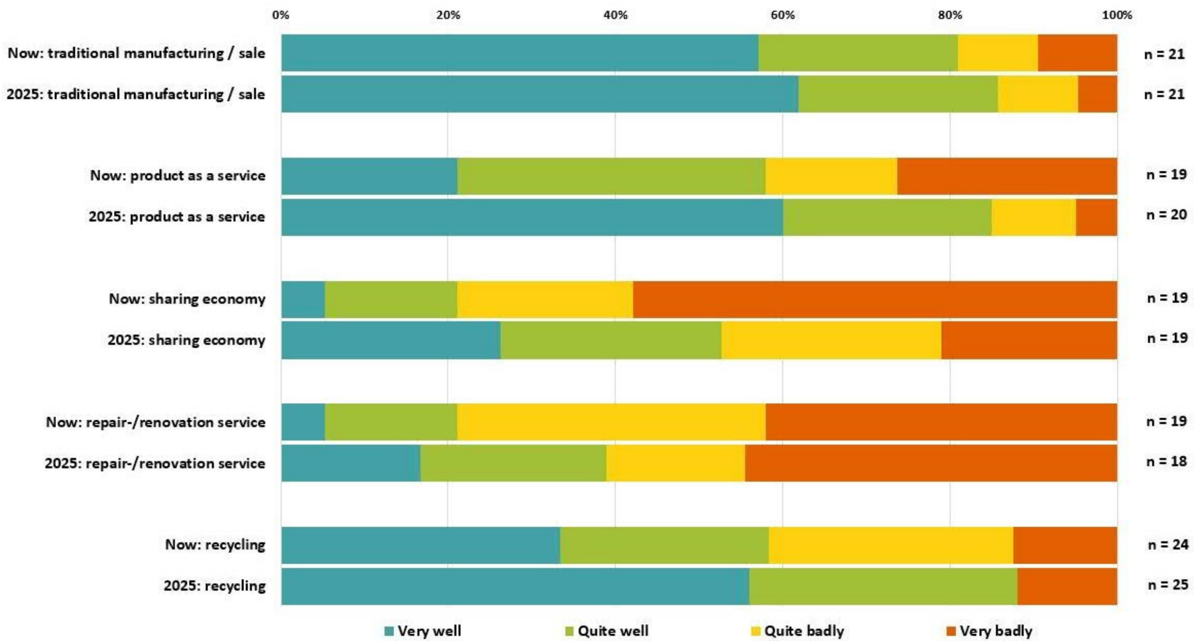

Figure 6 Views of Telaketju partners how different kinds of model describe their business now and in 2025

Telaketju partners have already used recycled or reused textiles in their business/activities to some extent. Over half of the partners were using or were willing to use sorted end-of-life textiles. One third were also interested in fibre, yarn, textile chaff and edge trim waste. The most important recycled materials were 100% cotton, 100% wool and 100% polyester, while, for example, cotton/polyester blends were important only to a bit over fourth of the partners and interest towards other blend textiles were negligible. In addition to material composition, other important information regarding materials were cleanliness, the history (for example pre- or post-consumer, where collected or who has processed), chemical usage and colour, see Figure 7.

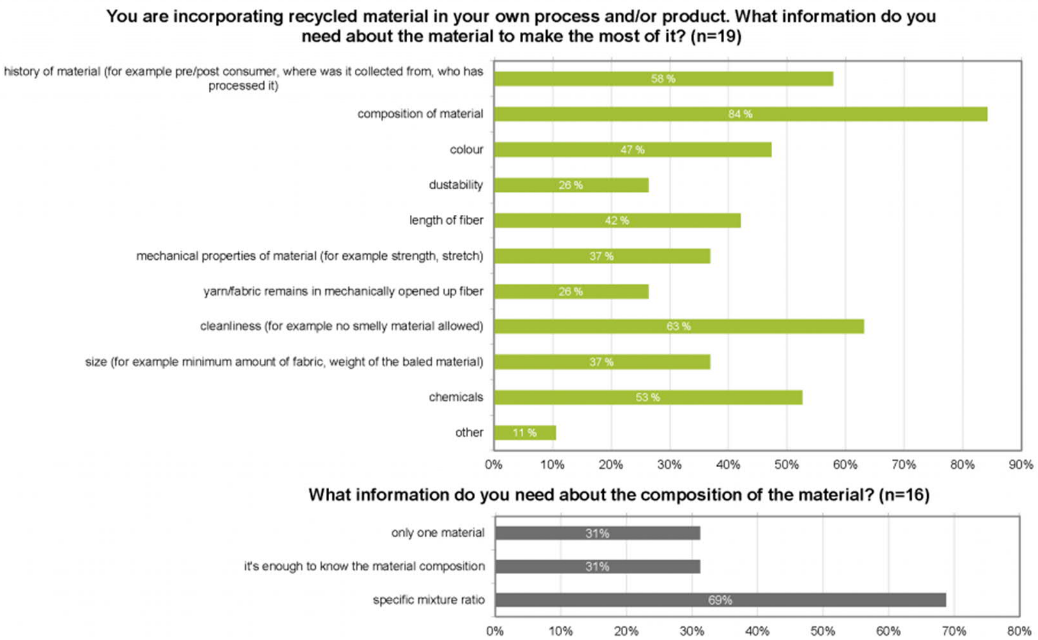

Figure 7 Important information regarding the recycled materials

Corporate social responsibility means that the company is working to increase sustainable development in the company. The activity of a responsible company is reliable, economic, socially acceptable and respects the nature.[2]

Social responsibility plays a big part in the Telaketju companies' and organizations' business. About one third of the companies answered that it is documented in their strategy. It is an important focus of the business strategy for all the participants, however. Activity is built depending strongly on responsible action in social, ecological and financial ways. Local manufacturing, the choice of materials and production custom are based on social responsibility in many of the answers. Being socially responsible can even be an economical advantage for businesses. More than four out of five businesses have customers that want to know about the social responsibility of products and services.

Sustainable development is an ongoing and structured process where society undergoes changes with the aim of securing desirable living conditions for the current and future generations. This means that environment, people and economy are taken coequally into account in decision making and in activities.[3] Sustainable development in business has to take into account all the same principles.

Almost four out of five partners think that sustainability is an important factor to their clients, and, approximately, the same amount said that clients ask about the social responsibility strategy of the company. This is quite a clear sign that people are becoming more and more aware of the environment and how their choices affect it.

Telaketju 2 BF project started with a background survey to map the starting points for the public project. The survey was sent to companies and organizations participating in the Telaketju 2 project. Results were used for refining the project plans. The survey had 25 responses in total, ranging from micro and small businesses to large ones, offering many kinds of products and services from clothing to waste management companies and consultancy services. See more details in https://telaketju.turkuamk.fi/uutiset/companies-interested-in-sustainability/

2 https://www.kuluttajaliitto.fi/tietopankki/turvallisuus-ja-riskit/yhteiskuntavastuu/
3 https://www.ym.fi/fi-fi/ymparisto/kestava_kehitys/mita_on_kestava_kehitys

2 Sustainable Business Models

This section focuses of novel business models and their application in the textile sector. The work included literature and a more theoretical part summarized in Chapter 2.1, and practical part summarized in Chapter 2.2.

2.1 Novel Circular Business Models for Textile Sector

Circular business models are needed to achieve the aims of circular economy. Adopting the circular economy principles in companies requires multiple innovations: in products, services, processes, and in business models. (Antikainen *et al.*, 2020). In a circular economy, products and materials continue to circulate in so called “loops” for as long as they can provide value, while simultaneously promoting activities that lower the need for the material per unit of value produced. These activities include, for example, service-based offerings such as rental services, the creation of more durable and leaner products (Ranta *et al.*, 2018). Renting or offering product-as-a-service is a way to embrace the circular business models (Antikainen *et al.*, 2020). These are called novel circular business models.

Value proposition in circular economy. We studied novel business models by using literature review, and in workshops with companies. We observed that, currently, the fashion industry is looking for more sustainable and circular solutions and clothing-as-a-service (CaaS) is one of the most promising ones. We studied value propositions of CaaS model based on the framework shown in Figure 8 (framework modified and partly adopted from earlier studies, see Antikainen *et al.*, 2020).

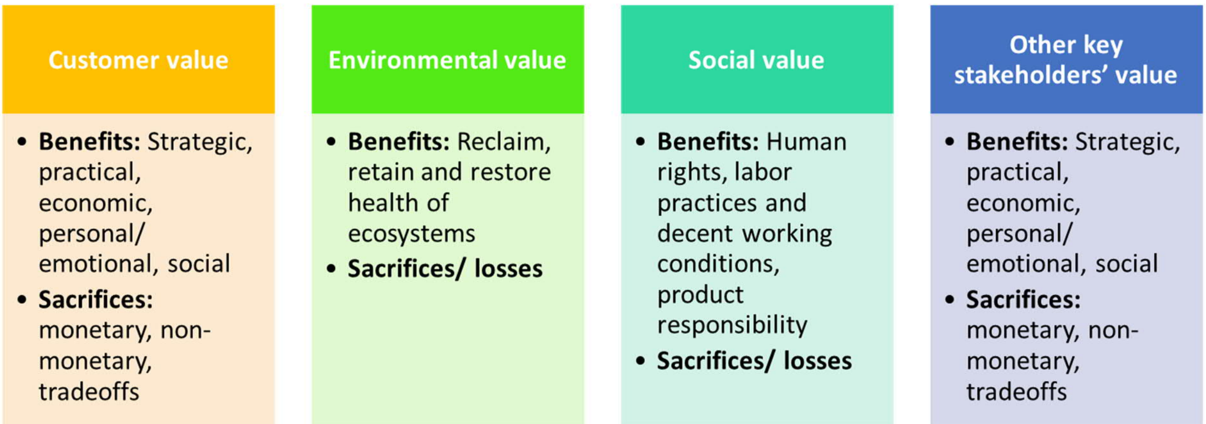

Figure 8 Framework of the value proposition study (Antikainen et al.*, 2020)*

Circular value propositions, benefits and sacrifices of CaaS model evaluated using this framework are summarized in Table 2. It seems that the CaaS model has a potential to create multiple kinds of value for the customers including economic, practical and emotional or social benefits. Thus, it seems that there are also a plenitude of still untapped value creation opportunities, for example, related to adding personalised services and increasing the communality among customers. However, one of the challenges of CaaS is to evaluate the impacts for the environment and society. (Antikainen *et al.*, 2020)

In Telaketju 2 we focused on the novel circular business models in the textile sector. In addition to literature review, we organized workshops. These were organized online due to the COVID-19 situation. The first workshop was organized in April 2020 - three companies participated in the workshop. The results of this workshop have been used as research data, analysed and published as a conference presentation and related research paper in English (Antikainen *et al.*, 2020). Another research paper was written combining results from the business model and consumer studied (see Chapter 3) - this is in Finnish (Antikainen *et al.*, 2021).

Table 2 Framework for circular value propositions of CaaS (Antikainen et al., 2020)

	Benefits	**Sacrifices**
Customer value Economic	• Control of costs and property management • No investments needed	• More expensive than buying
Practical	• Lower risks • Easiness through full-service and selection • No storage needed • Flexibility and selection testing is easy • Knowing the quality • Possibility to test information and learning • Saving time	• Doubt about the compliance • Fear of destroying a cloth and the related argument • Requires more planning • Limited selection
Emotional/Social	• Good conscience of ecologic choice • Inspiration and status • Community of consumers • Entertainment	• Disappointment of not getting new clothing • Doubt about privacy • Feels strange • Concern of the hygiene
Environmental value	• Whole Life-Cycle is planned • Longer life, less production of raw material by optimisation of use • Efficient maintenance • Minimising of the unnecessary purchases • Sustainable and responsible disposal • Less physical space, less travelling • Shifting of the general opinion about consuming	• Transportation increases energy consumption and emissions • Washing of clothes • Unnecessary production • Energy consuming digital services • Possible rebound effect
Social value	• Increasing employment • Efficiency in waste management • Equality • Path leader • Responsibility • Demand for responsible production • Communality • Synergies for local businesses	• Expenses of sustainability • Decrease of demand and employees for traditional fashion businesses
Other key stakeholders, value	• Life-cycle is planned • Image of responsible company • Brand awareness • Use of spare inventory/items • Stronger customer relationship	• Decrease in order volumes • Claims of 'green washing'

Branding and communication. Sustainability in business activities, branding and marketing communications should be continuously and systematically discussed and re-evaluated in companies in order to successfully implement novel circular business models. Applying the environmental, societal and financial sustainability perspectives into business models and into the marketing strategy require careful consideration and possible re-formulation of companies` fundamental values, including the company`s vision and mission. The fundamental company values are reflected in the brand value, implying to the customer`s evaluation of the product`s or service`s value in relation to other brands (Grönroos, 2010). To address another aspect, customer value proposition should reflect the sustainability focus of a company, as it articulates and identifies the company's aim to provide value to the customers and it is a key mechanism of communication and strategic positioning (Payne *et al.*, 2017). In sustainable business models, the value propositions should include measurable ecological, social and economic values and the stakeholder network perspective should be taken into account in addition to the customer perspective (Boons & Lüdeke-Freund, 2013).

The knowledge and know-how of the consortium partners regarding sustainability in business activities was enhanced by organizing a set of 2 workshops (1.10.2020 & 29.10.2020) and 2 webinars with special focus on different aspects of marketing strategy e.g. branding and marketing communications: 28.5.2020 https://telaketju.turkuamk.fi/webinaarit/mista-tietaa-onko-yritys-vastuullinen/ & 26.11.2020 https://telaketju.turkuamk.fi/webinaarit/vaikuttaminen-ja-vastuullisuudesta-viestiminen-sosiaalisessa-mediassa/.

2.2 Business Models in Practice

Business models were co-innovated with companies within workshops. Altogether five ideas rose from these workshops into practical *Quick Trial*. Some of these trials included practical testing of a business model or new concept namely *Everyday clothes rental concept* and *Worn and loved* (in Finnish 'Puhkirakastettu'), one looked for technical solutions for *The removal of logos from work wear at clothing-as-service model*, while the other two focused on visualizations of a model, thus helping companies to implement such a model in the future. These include *Wool product life cycle* and *Clothing as a Service visualizations.*

Telaketju held two textiles as a service workshops with companies in the spring 2020. The first one was Clothing as a Service and the second one Returning as a Service. All the Telaketju companies were invited to both workshops. Five companies found Clothes-as-a-Service business model to be relevant to them, and four were interested in the Returning-as-a-Service business model.

Quick trial - Everyday clothes rental concept

Pure Waste Textiles took the idea further to examine it in a quick trial *Everyday clothes rental concept*. The purpose of the pilot was to find out what kind of textiles as a service- product packages, composed of Pure Waste's products (examples in Figure 9) are of interest to the consumer.

Figure 9 Pure Waste clothing available in rental service concept

The pilot was successful. It brought new information about peoples' rental willingness, bottlenecks, what is functional in practice and what is not, and in addition, what kind of clothes people want to wear as everyday clothing. People, who attended the pilot, thought that clothing rental will become more popular in the next three years. We received a lot of new development ideas, wishes and notes about unworkable things. Participants saw this trial as an interesting opportunity and they were happy to be involved, having someone else take care of their garments. Both saw the potential in renting, especially everyday clothes for work in a smart yet casual style.

Based on the pilot findings, it is worthwhile, that an everyday clothing rental service should be further developed in the future and should generate a second pilot from this same subject. In the second pilot, at least, a variety of package and participation options as well as a digital platform to support renting, would be deployed.

The pilot was implemented as a two-month pilot period in the autumn of 2020. During the starting phase, the pilot attracted a lot of interest and over 270 candidates were applied to the pilot. Only 20 of them were chosen, but a lot of information were gathered already from the applications. Two pilot participants were interviewed for a blog post on their experiences and views on the pilot, as well as the clothes as a service model in general. The blog post is available in Finnish at https://telaketju.turkuamk.fi/blogi-fi/arkivaatteet-lainattuina-kotiin-kaksi-kuukautta/

Quick trial - Puhkirakastettu

Vaatepuu (clothing rental service) wanted to encourage customers to extend the life of their clothes by maintaining and repairing them. The quick trial based on this idea was called *Puhkirakastettu* ("worn and loved"). In addition, the goal was to make used and repaired clothes more visible in Vaatepuu.

In cooperation with Vaatepuu and Turku UAS, Puhkirakastettu clothing labels were invented. With Puhkirakastettu clothing labels, customers can see how the garments they wish to rent have been repaired and maintained, in other words they can see the "health" that the clothing has gained. Customers and clothing rental services mark the clothing labels if the garment is repaired. The idea comes from the video game world, where collecting hearts gives you extra life and more health. This theme was desired to utilize also in the Puhkirakastettu social media campaign that was arranged in Instagram.

It is still difficult to assess the effectiveness of the quick trial because the Puhkirakastettu clothing labels experiment has been carried out for a relatively short time (since January 2021). It is also still difficult to measure the effectiveness of Puhkirakastettu's campaign in social media at the moment. The campaign was positively received by social media. In addition, the Puhkirakastettu clothing labels were praised in the social media and a discussion around the topic has arisen.

Initial work was carried out and e.g. labels developed as collaboration between Turku UAS and Vaatepuu. Vaatepuu started to use them in January 2021. More information about this trial is available in Finnish https://telaketju.turkuamk.fi/puhkirakastettu/

The removal of logos from work wear at clothing-as-service model

The purpose was to solve how different logos can be exchanged from work wear in a cost-effective way, without compromising the appearance of the product. One of the critical steps in the work wear rental cycle is related to company logos, and exchanging them.

A correct answer to technical logos exchange was not found. Solutions were accessible to the systemic level. The challenges of work wear recycling have been generally well known around the world, and there are many ongoing projects about this theme. The fast and smart interchangeability of the logos must be taken into account already at the design stage. The materials of the future may offer completely new ways to fix logos to textiles.

Work was carried out as literature review. See publication in Finnish https://telaketju.turkuamk.fi/blogi/logot-uusiksi-ja-tyovaate-kiertamaan/

Quick trial - Wool product life cycle

Kehräämö Mustalammas participated in the *Clothing-as-a-Service* -workshop. They wanted to lengthen the life cycle of wool products. The quick trial was done in the form of a visualisation that shows which parts in the process still need developing. The name of the quick trial was “Wool product life cycle". It hopefully supports the broader utilization of raw wool in Finland and the circular economy of wool products.

The visualisation (see Figure 10a) is based on the process of Kehräämö Mustalammas and the final result may differ from the processes of other companies. It lacks the circulation of wool into yarn and into textile products made from yarn, which is also possible.

The idea was to visualise the life cycle of wool from raw wool to a wool product considering the sustainability. The purpose of the visualisation was to show what processes the product goes through before it reaches the customer and what happens to it at the end of its life cycle. By mapping the life cycle, it is possible to develop product design, production and increase the value of the wool product. The visualisation is available on the Telaketju website (in Finnish): https://telaketju.turkuamk.fi/kokeilu/villatuotteen-elinkaari/

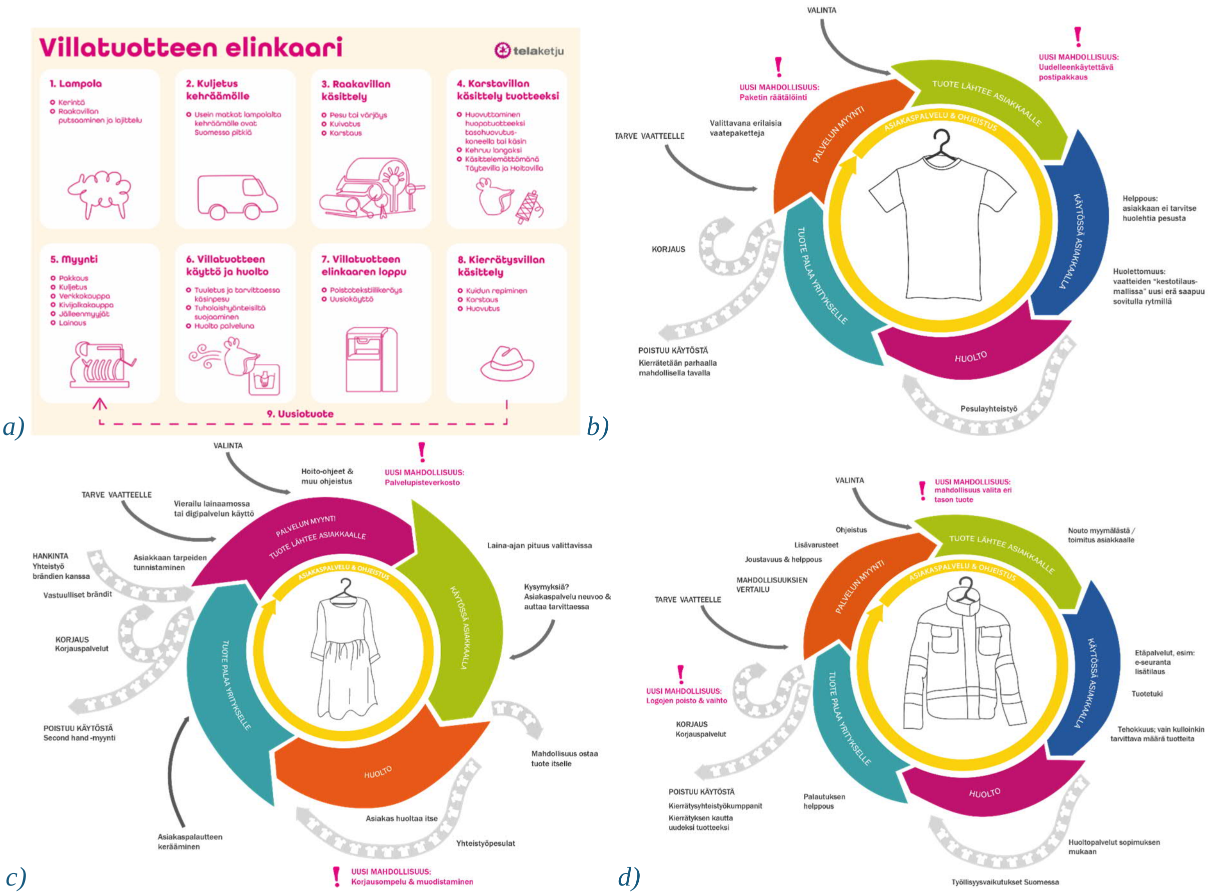

Figure 10 Quick trials implemented as illustrations (in Finnish) a) Wool product life cycle and Clothing as a Service b) for a brand, c) for consumer rental and d) for work wear

Clothing as a Service visualizations

During the workshops, a point came up, that even if we think Clothing as a Service is one business model companies may adjust to develop their business, it actually works quite differently depending on the company’s field. Participating companies represented different types of businesses: work wear company, consumer clothing rental and a brand’s own rental service. These three different clothing as a service -business models were visualized in the illustrations (see Figure 10b-d).

In the future, these visualizations can be used as a communication tool with customers, investors etc. It can also help companies design their business model and compare different business models with each other.

The visualizations were done based on the tables gathered in the workshops, end results of the experiments and finalized with comments from the companies. The task consisted of two main parts: carefully studying the result tables of workshops and the actual design work. The design work was carried out by benchmarking and analysing existing infographics, sketching and iterating process. A circular infographic type was chosen, because it illustrates the flow of the process naturally. Telaketju2 visual guidelines were followed when fonts and colours were chosen. In the final phase the companies were also invited to comment on the illustrated infographics.

3 Consumer Attitudes towards New Models and Recycling

This section focuses on consumer research. We studied consumer attitudes by using a three-part consumer survey: 1) survey with Finnish consumers, 2) survey with young consumers from different EU countries and 3) workshop with Finnish consumers.

The aim of the Finnish survey was to find out consumer's attitudes towards recycling in general and towards different circular economy business models of textiles: what kind of values do consumers seek and receive from solutions, and what kind of circular economy business models and services do they prefer. Three different models were evaluated: 1) New garments from recycled fibre, 2) New products from used textiles i.e. remaking, and 3) Clothes-as-a-Service (CaaS). The aim of the international part of the survey was to compare the attitudes of young adults (aged 20-29 years) in Finland and in a few other European countries. The aim of the workshop was to deepen our understanding of consumers attitudes on garments produced from recycled fibre, and to discuss with consumers about three different themes: the collection of end-of-life textiles, the shopping of garments made from recycled fibre, and consumer communications related to these products.

Finns are known to be active at recycling and nearly 90% of respondents recycle magazines and papers as well as pledged beverage bottles and cans. In the case of clothes and other textiles, more than half of the respondents said they recycle them. They tend to end up using textiles for their own use and if this is not possible, they recycle the textiles so that someone else can use them, i.e. give them to acquaintances and relatives or sell them at flea markets. About a third of respondents throw unusable textiles in the trash.

In general, Finnish consumers were pleased that the collection possibilities for end-of-life textiles would be improved and that the fibres could be utilized in new textiles. A majority, 84% of consumers would very likely or somewhat likely to dispose of unusable textile waste for separate collection. A driver for this behaviour is that consumers want to get rid of unnecessary goods. The most popular collection point for end-of-life textiles would be the same place where other recyclable materials are already collected nowadays. Collection needs to be easy and it has a particular impact on consumers' willingness to deliver unusable textiles for collection. Consumers also feel that by delivering unusable textiles for collection they can act responsibly and protect the environment.

Also 20-29 years old consumers were positive about having separate textile waste collection: 89% of European and 80% of Finnish young consumers would very likely or somewhat likely dispose of unusable textile waste for separate collection. The reason behind the young consumers' willingness were the easiness of taking textiles to the collection, they would like to act responsibly and protect the environment, and information about how the recycled textiles are reclaimed (see Figure 11). The information part was more interesting for other European consumer than Finns.

The workshop participants had a very positive view towards textile collection for recycling, and all of them would very likely take their unusable textile waste to a separate textile collection point when it becomes possible. They liked that Finland has taken the role as a forerunner in collecting textile waste, and saw that this could be a huge advantage for the country in the future. Consumers felt that it would be a natural part to collect the textiles alongside the other material collection, like paper, glass, and plastics. They emphasised that there should be enough collection points available and it should be clearly communicated which kinds of garments and other textiles could be brought to the collection point. The most preferred locations for the collection points were in the residential area and residential building area, close to other collection points. The easiness and location of the collection points were discussed as motivational issues for the consumers. However, consumers also raised the responsibility of the companies. They would be willing to see that the companies could more effectively utilise the unused textiles, and could take textile recycling as a part of their communication and marketing.

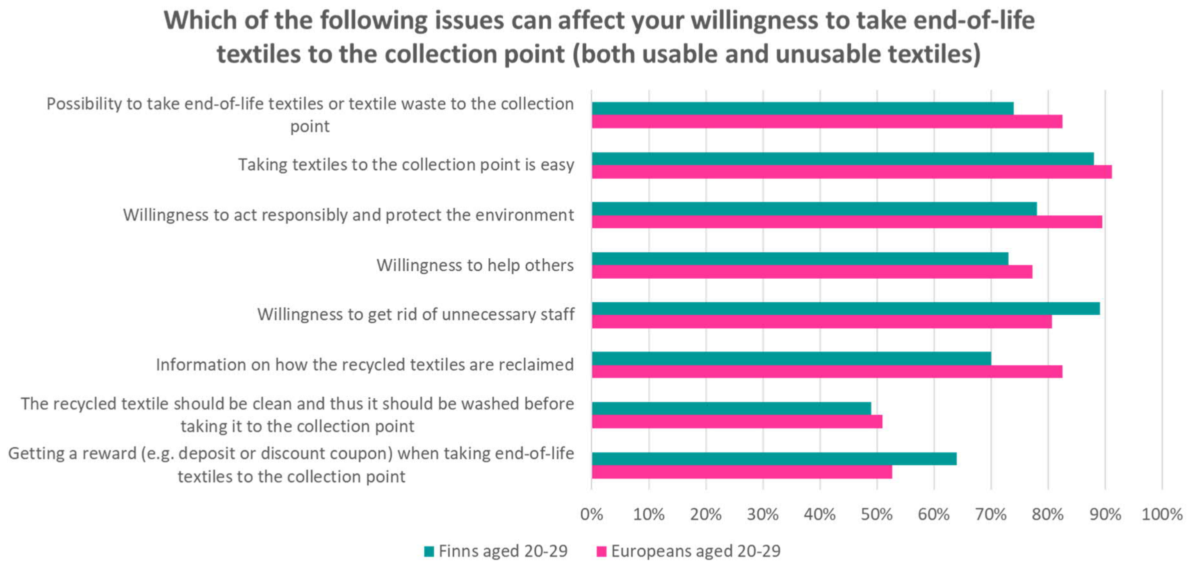

Figure 11 Issues that may affect the willingness to take end-of-life textiles to the collection point (comparison between Finns and Europeans aged 20-29)

3.1 Use of Recycled Fibres

The first model evaluated by consumers was called *Producing new garments from recycled fibre*. In this model, the idea is that textile waste can be recycled as a new textile fibre, which are further used in the fabrication of new products, for example, of garments and home textiles. Products made from recycled fibres have similar characteristics and quality as products made from non-recycled fibres.

Most of the Finnish respondents (75 % of all age groups) were very or at least quite interested in buying products made from recycled fibre. They stated that products made from recycled fibres should be the ‘new normal’ and available for everyone. The most important factors in making a purchase decision for products made from recycled fibre are the product comfort, price, product quality and durability, and ease of maintenance. These were followed by recyclability and ecology, and responsibility. More than 70% of respondents felt that products made from recycled fibre are not sufficiently available, and doubted the quality and durability of the products.

European young consumers were a bit more interested in buying products made from recycled fibre than Finns: 91% responded to be very interested or quite interested, while among young Finnish consumers, the same value was 73%. For example, one respondent (male, 25) told that “*I would rather buy products made from recycled fibres than products made from new materials, but I still prefer to end up with old clothes and buy used clothes. However, a garment made from recycled fibres is not necessarily ethical or ecological, so buying unnecessary clothes should be avoided in the first place*”.

Compared to the Finns, the European consumers were more interested in different kinds of information about the garments (Figure 12). The most important information of the products made from recycled fibre for European consumers were sustainability, used materials and the amount of recycled fibre. In Finland, the young consumers also preferred information about used materials, but also the manufacturing country, and care and use instructions.

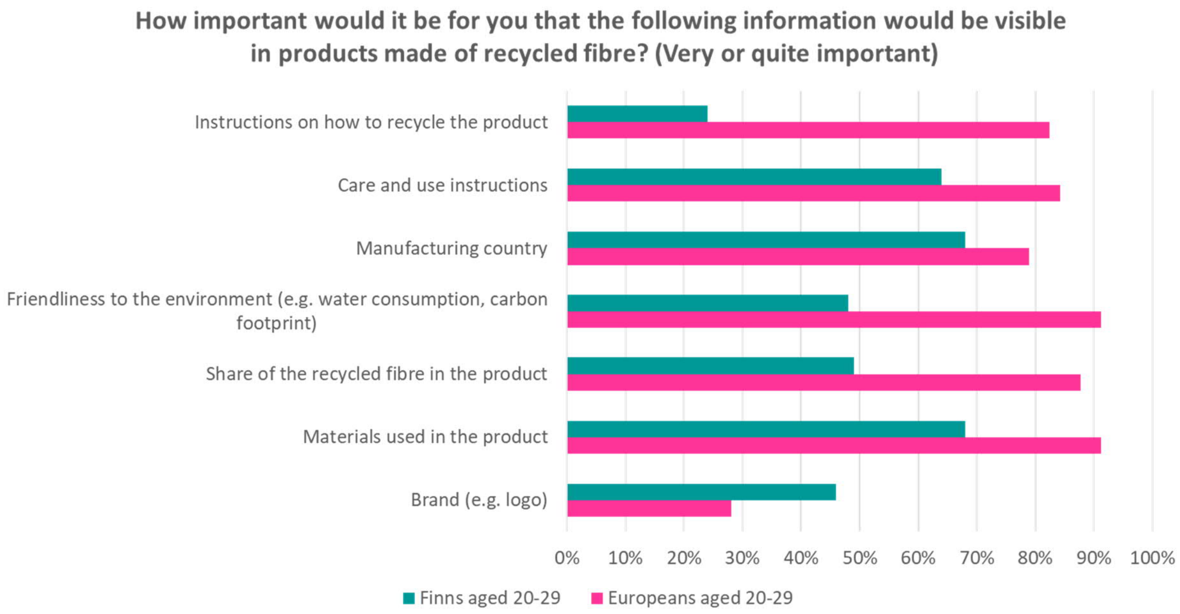

Figure 12 Importance of different product information of products made of recycled fibre for consumers aged 20-29 (comparison between Finns and Europeans)

For young consumers, the most important factors in making a purchase decision for products made from recycled fibre were the product's comfort in use, price, as well as the quality and durability (see Figure 13). One of the respondents (male, 29) also pointed out the importance of transparency in pricing: "*I would like to receive information about where the price of the product came from. Who has been paid and how much for e.g. raw material manufacturers, textile manufacturers, designers and seamstresses, etc. from which I could be sure that the garment was produced ethically and not just for the highest possible return*".

The least important factors in the purchase decision were the impact on your own image, the brand and the fact that others have recommended the product. European respondents considered the recyclability of products, information on the origin of fibre and material, and the chemicals used to be more important than Finns. In addition, the ecology and responsibility of the product were more important to international respondents than to Finnish respondents. Respondents felt that there is not enough information available about recycled garments. For example, one respondent (female, 25) commented that "*I think there needs to be a clear marketing or branding effort for recycled fibres that also serves as an educational tool for consumers so we know what to look for, why it matters and what makes the process unique*".

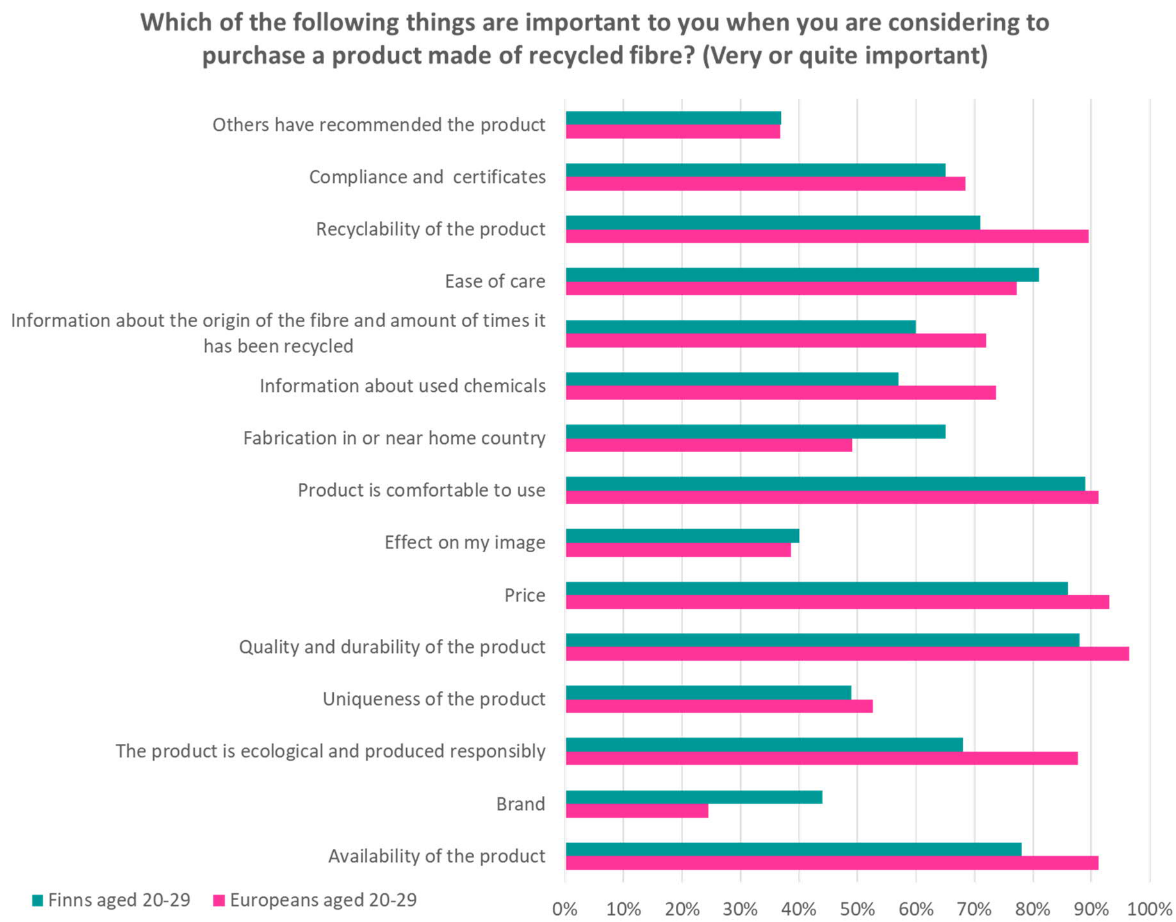

Figure 13 Factors that are important for young consumers when purchasing products made of recycled fibre (comparison between Finns and Europeans aged 20-29)

Most respondents thought that a product made from recycled fibre should be priced the same as a similar non-recycled fibre product. The international young respondents also agreed that a product made from recycled fibre could be more expensive (see Figure 14) and one respondent (female, 26) commented that "*I think clothes made from recycled fibre is a sensible and environmentally friendly idea. I myself could pay a little extra for such products, but I know that many consumers make their purchase decision based on price. For the sake of the environment and the common good, it would be crucial to make ecological options trendier and more competitive*".

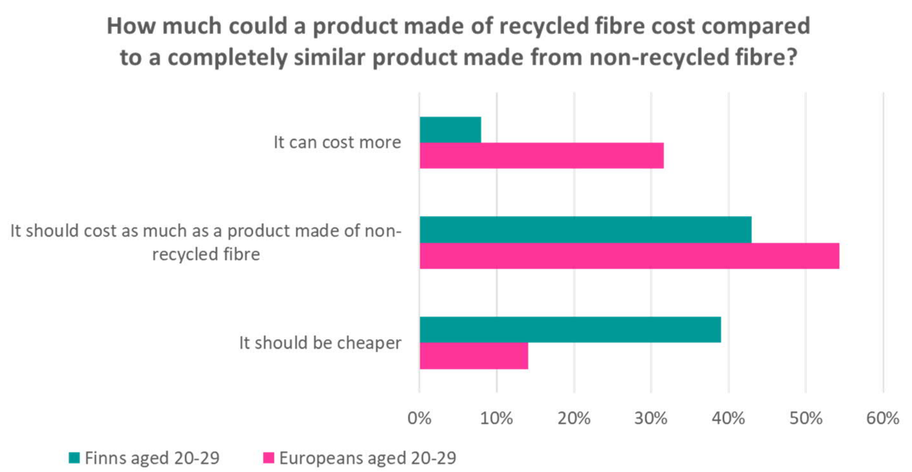

Figure 14 Young consumers' opinions about the price of the products made of recycled fibre (comparison between Finns and Europeans aged 20-29)

Garments made from recycled fibre was of interest to the workshop participants; four participants were very interested and another four quite interested in buying clothes made from recycled fibre. Some already used products made from recycled fibres. Participants also mentioned that they have seen more and more novel markings/labels on the garments for sale related to the recycling and sustainability, and they were very happy that more sustainable garments are coming to the market. However, consumers were not sure how to evaluate the different garments and producers, they were not sure if they are able to trust them in all the cases. In addition, the participants considered that a product made from recycled fibre does not automatically mean that it is organic or sustainable. Consumers were requiring much more transparency and information available from the companies. They would like to find information, for example, about the origin of different materials, production process, used chemicals, carbon footprint, from company's or brand owner's website, via the QR code that could be available in the garment label.

Workshop participants told that their shopping behaviour has changed during the past years and they mainly made well-thought-out garment purchases, especially when buying new clothes. More impulse purchases are made in second hand shops. Most participants familiarized themselves with the products carefully before making a purchase decision and purchased only for need. The most important issues for consumers when they are making the buying decisions were the quality and durability of the product (7), ecology and responsibility (6) and the price of the product (4). Participants were willing to pay more for the products made from recycled fibre if they are high quality. In addition, the money should be directed to the producers and not to the "pocket" of the brand. The prices of products should be competitive, and it should be possible for the majority to buy them, regardless of income level. However, there is no need to compete with fast fashion prices. Consumers also mentioned that usually awareness of the textile industry and different possibilities affects the willingness to pay more. Transparency in product pricing was perceived as important and it was hoped that it would be brought more visible. Communication on pricing must be in a form that consumers can understand.

The communication about garments made from recycled fibre must be sufficiently informative and provide reliable information on the concrete actions of companies, for example, to promote environmental friendliness. "Green washing" and offensive communication were viewed negatively, it was even perceived as intrusive and influenced the willingness to use the company's products. Communication that was produced by an outsider rather than by the company itself, was perceived as reliable, like documentaries on television.

3.2 Remade Textiles

The second model evaluated by consumers was called *New products from used textiles*. In this model, the idea is that used textiles, for example, cast-off home textiles like tablecloths and hotel curtains as well as leftover material from the textile industry are utilized in the manufacturing of new textile products. These products are of high quality, unique and ecological.

Most (69%) of the Finnish respondents were very or quite interested in buying products made from used textiles. In other words, this was almost as interesting for consumers as the previous model where new products were made of recycled fibre. The products made of used textiles that consumers would prefer to purchase were home textiles, bags and clothes. Similarly, to the first business model, the most important factors in making a purchase decision for products made from used textiles are the product comfort, price, product quality and durability, and ease of maintenance. They were also willing to buy products manufactured domestically or in local areas.

Also young consumers, 20-29 years old, liked the idea of buying products made of old textiles. Especially European consumers from which 77% were very or quite interested in buying products made from used textiles. Among young Finnish consumers, the same value was 62%. For example, one respondent (female, 25) told that: "*The idea is good. It's always good to think about how to take advantage of all the materials before their final disposal. The main issue is that new materials and products are not always needed before we can still use old materials that are available*". In general, material used, environmental friendliness, and care and use instructions were the most important information about the products made from used textiles for the young consumers. Compared to the Finns, the European consumers were more interested especially in garments' environmental friendliness and instructions on how to recycle the product, but also about treatments made for the material and used chemicals and materials in the product (see Figure 15). The Finns were a bit more interested in the brand, manufacturing country and original use of the textile compared to European participants. For example, one respondent (male, 28) was worried about "*If the materials have been used before, for example, as carpets in a dirty public place, are the new products made out of the used textile clean for sure*".

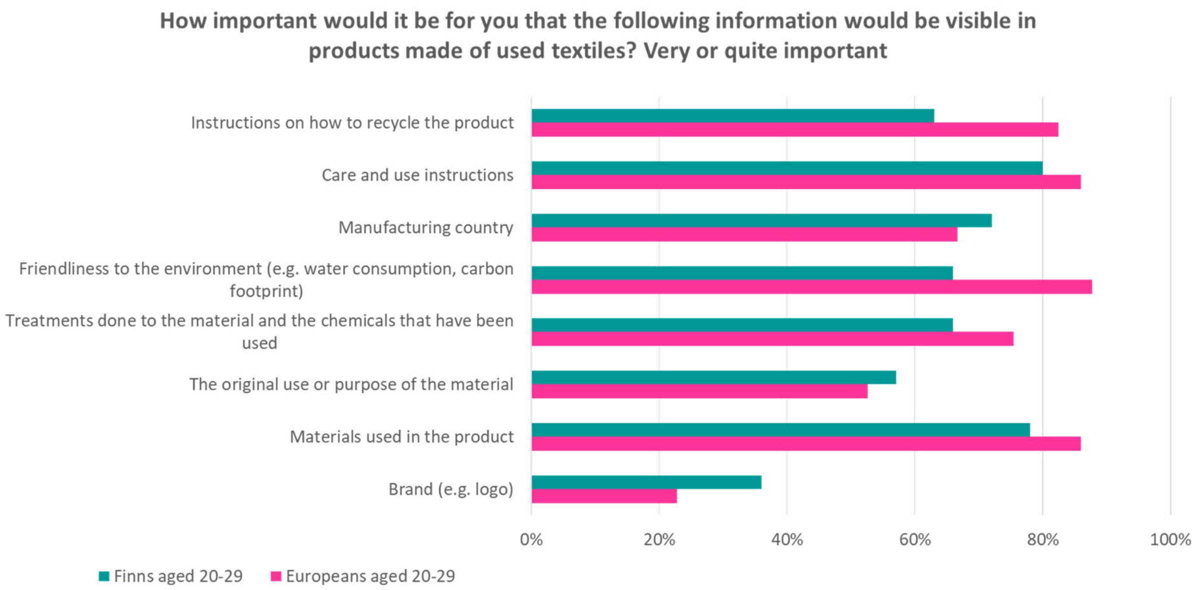

Figure 15 Importance of different product information of products made of used textiles for consumers aged 20-29 (comparison between Finns and Europeans)

The most important factors in making a purchase decision for products made from used textiles are the product's quality and durability, price, and ease of use and care (see Figure 16), similarly to the products made of recycled fibres. The least important factors in the purchase decision are the impact on your own image, the brand and the fact that others have recommended the product. Still, these issues were more important to the young Finnish consumers than to European consumers. International respondents considered the ecology and responsibility, recyclability of products, information on the origin of material, and the chemicals used to be more important than Finns.

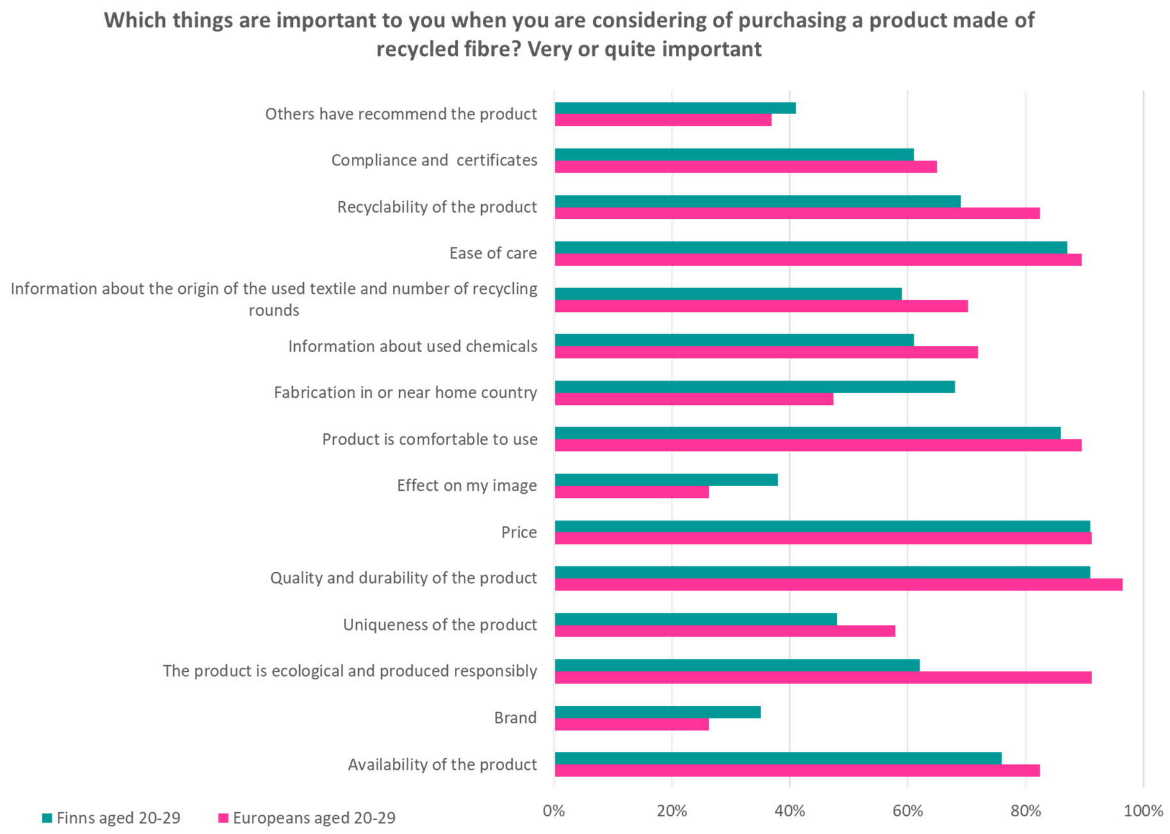

Figure 16 Factors that are important for young consumers when purchasing products made of used textiles (comparison between Finns and Europeans aged 20-29)

The majority of respondents were of the opinion that a product made from recycled fibre should be priced the same as a similar non-recycled fibre product, or they should be cheaper (see Figure 17).

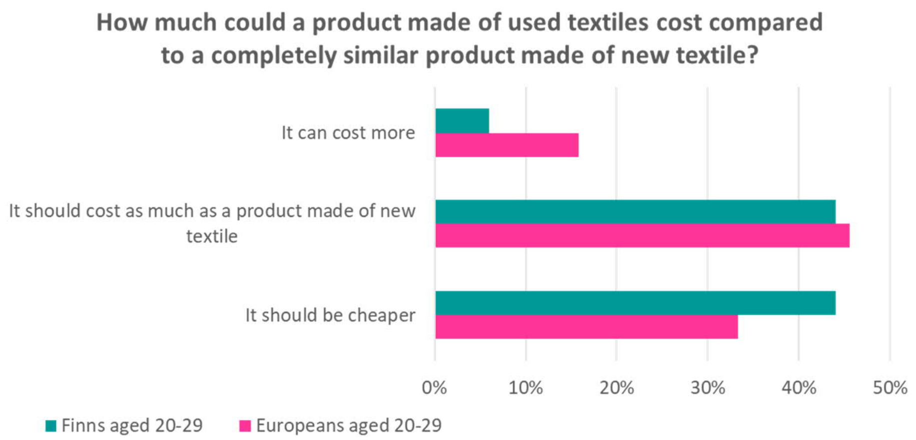

Figure 17 Young consumers opinions about the price of the products made of used textiles (comparison between Finns and Europeans aged 20-29)

3.3 'Clothes as a Service' Business Model

The third model evaluated by consumers was called '*Clothes as a service' (CaaS) business model*. The idea of the model is that the consumer is offered used clothes and accessories for temporary use. The service use is based on a membership, which can be, for example, temporary. It is possible to view and try the clothes on in the store, or they can be ordered from the online service to be delivered at home.

At the end of the loan period, the clothes can be easily returned. The service will also include a repair service that makes sure the products will be in good condition during the use.

The CaaS business model did not arouse much interest among the Finnish respondents, only 34% were very or quite interested in using the service. A one-time payment was the most popular among the respondents over the multiple used card, monthly fee or subscription. Consumers were most interested in purchasing formal wear. The service price, the appearance and quality of the products, as well as the easiness to use the service were considered to be the most important factors to utilize the service.

Among young consumers the CaaS model was seen a bit more interesting concept, since 48% of European consumers were very or quite interested in using the service and, among young Finnish consumers, the same value was 36%. All of the participants were interested in purchasing especially formal clothing via the service (see Figure 18). The consumers were least interested in renting hats and sports or outdoor clothing via the service. One of the respondents (male, 26) commented that "*I think this concept is the most interesting for textiles that are not used frequently, or that are not wearables, like decorative textiles at home which someone likes to change from time to time*".

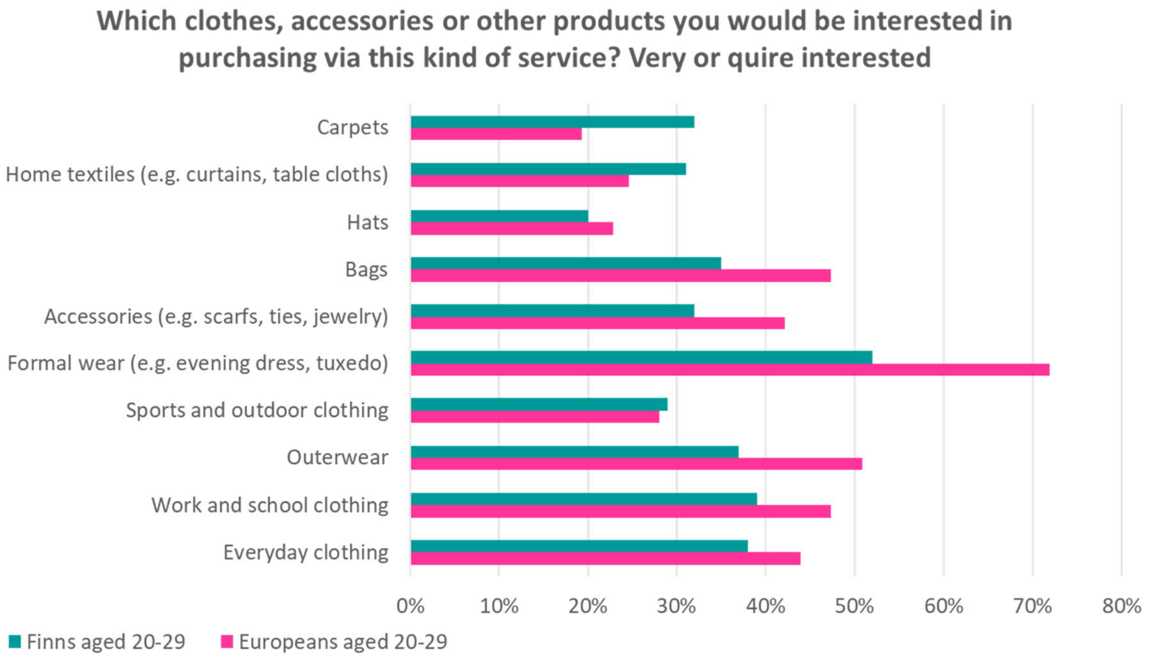

Figure 18 Products that young consumers are willing to purchase via clothes as a service (comparison between Finns and Europeans)

The most important factors in making a purchase decision via the service are the price of the service, the appearance of the product, and versatility in the product selection, as far as the easiness to use the service (Figure 19). Respondents pointed out their concerns related to the condition of the garments and, for example, one of the respondents (female, 24) pointed out that: "*The service has to make sure that the products are in a flawless condition before giving them to people. I was asking myself what happens if the user accidentally destroys the garment while using it*". In addition, another respondent (female, 29) brought up the hygiene aspect: "*The clothes should be hygienic. A person who has used the clothes before may have a disease, such as a skin problem, so this should be avoided and confirmed/certified by the service provider*".

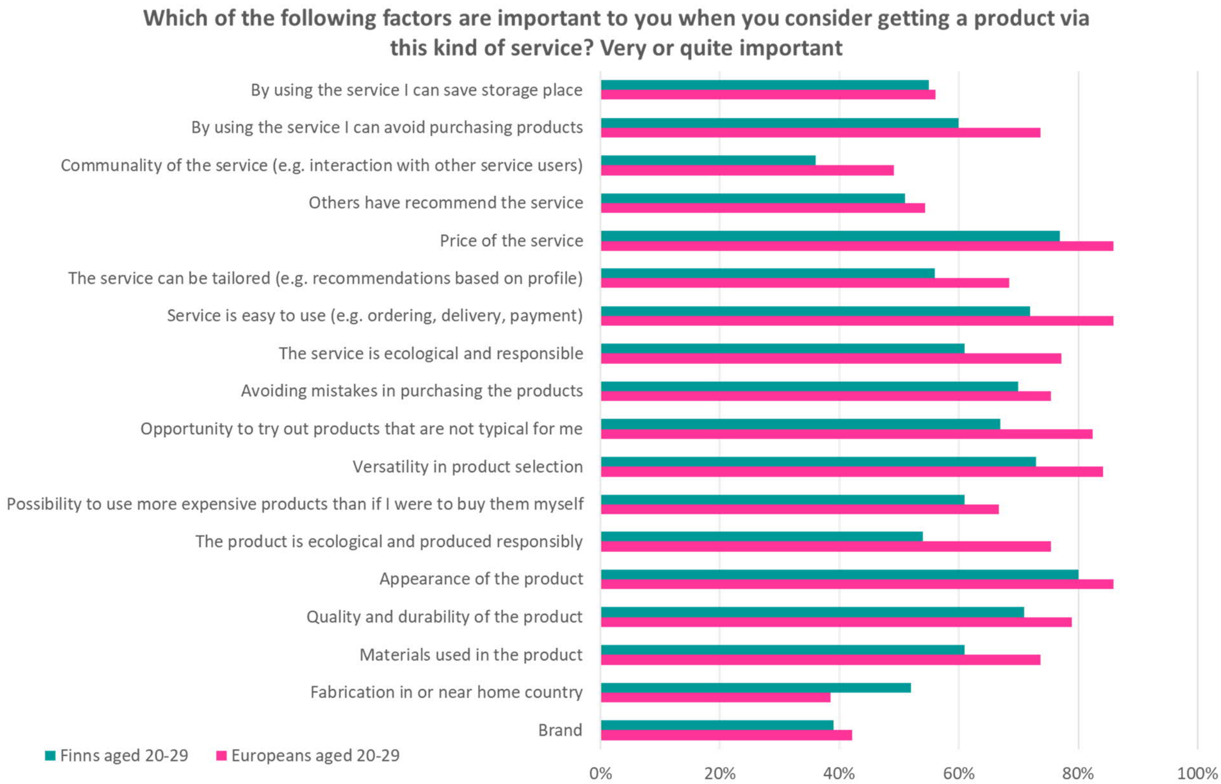

Figure 19 Factors that are important for young consumers when purchasing products via clothes as a service (comparison between Finns and Europeans aged 20-29)

From different payment methods the monthly fee was experienced as the most popular among European respondents, while most Finns were in favour of a single fare (see Figure 20). The least support was given to the subscription (fixed longer period commitment e.g. 6 months at a time) to use the service.

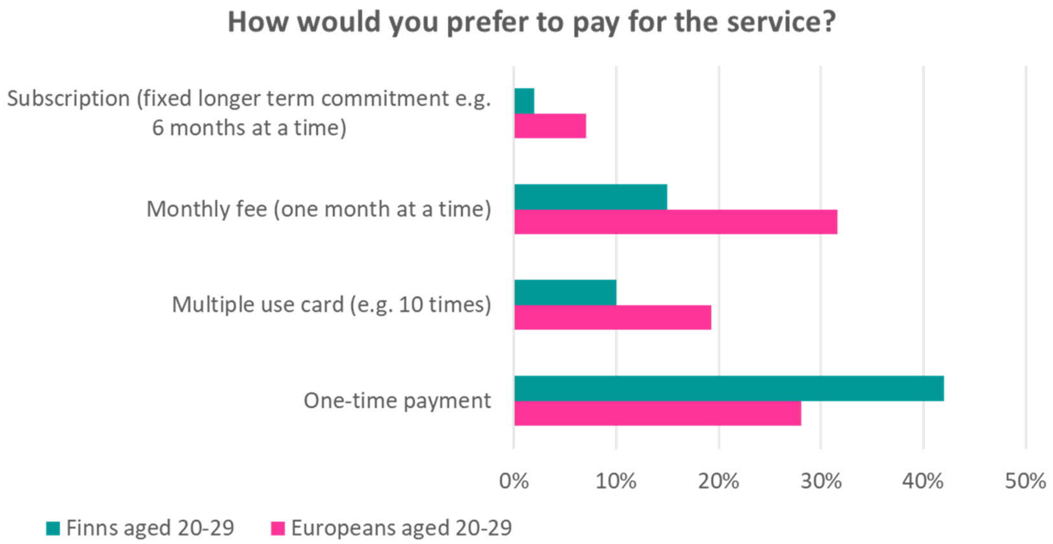

Figure 20 Preferred payment methods for clothes as a service among young consumers (comparison between Finns and Europeans aged 20-29)

3.4 Preferred Model and Conclusions

Consumers were also asked to choose which model they would prefer while purchasing clothes in the future: new garments from recycled fibre, new products from used textiles, clothes as a service, or would they rather purchase second-hand clothes or would they prefer to buy clothes as brand new. The business model, where the garments are produced from recycled fibre was clearly the most interesting for Finnish consumers, as well as for young consumers both in Finland and in other European countries (Figure 21).

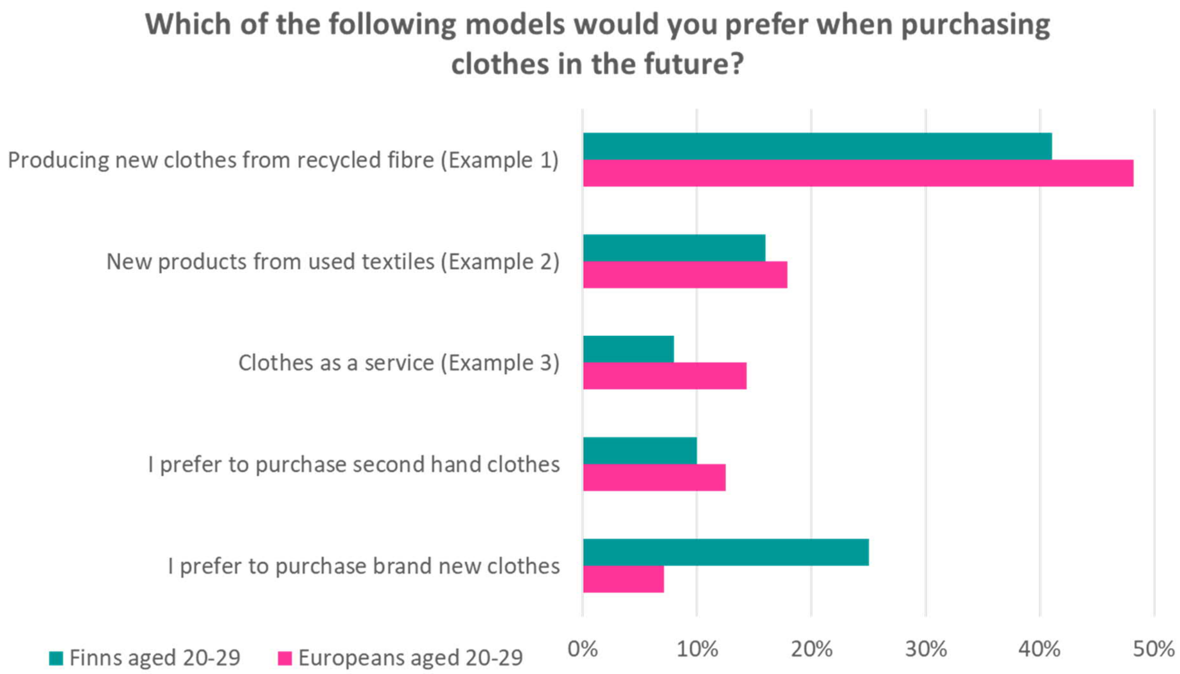

Figure 21 Most preferred model in purchasing clothes in the future among young consumers (comparison between Finns and Europeans aged 20-29)

In conclusion, the consumer research gave us valuable data about the consumers' attitudes of textile recycling, as well as their insight towards different circular economy business models and circular products from consumers in Finland and selected European countries. Based on the results, we are able to conclude that the time is ready for novel circular economy solutions also in the textile sector. Consumers and companies are aware of the limited natural resources and climate change and they are concerned about the challenges that these issues cause. It is understood that something needs to be done. Consumers both in Finland and other European countries really like the idea to utilise textile waste and used textiles to produce new clothes and other textile products. The attitude towards circular clothing is positive. The young consumers (20-29 years) in other European countries were more interested in these, compared to Finnish consumers of the same age. Circular clothing was seen as good as a new clothing, and in that sense those who would not wear second-hand clothes, would happily buy circular garments. Garments made from recycled fibre seemed to be the business model the consumers like the most compared to other studied models or the options to buy second-hand clothes or clothes made from non-recycled fibre.

In the previous study, we found out that, according to the consumers, circular garments should be more available on the market, and they should be branded as luxury items and a special edition that would be easily recognisable (Vehmas *et al.*, 2018). Here, it was seen that circular fashion should be a new normal and it should be possible for the majority to buy them, regardless of income level. The most important factors in making a purchase decision for products made from recycled fibre are the product's comfort in use, price, and quality and durability. Consumers need more information and, especially, more transparency to pricing to make purchase decisions and to evaluate whetherthe product is environmentally friendly or not.

Communication has a remarkable role in convincing consumers of the importance of sustainable consumption. For example, in this study, more than half of the respondents did not consider recycled fibre products to be particularly responsible and this might be due to the fact that they do not have enough information about producing and manufacturing recycled fibre products. In addition, consumers were not sure how to evaluate sustainability, responsibility or environmental friendliness of the different garments and producers, they were not sure if they are able to trust available information or them in all the cases. Therefore, the sharing of information is of great importance, especially in the marketing of such organic products. More information about the environmental and ethical aspects of the textile manufacturers and brand owners should be available and communication should be more visible and consumers were asking for much more transparency. The communication should be sufficiently informative and provide reliable information on the concrete actions of companies. “Green washing” and offensive communication were viewed negatively.

The consumer research of Telaketju 2 project consisted of three parts; 1) a quantitative consumer survey, an on-line questionnaire, in Finland (N=300); 2) a qualitative consumer survey in a few other European countries (mainly Germany, Sweden and the Netherlands, N=57 totally), the questionnaire was a shortened version of the version we used in Finnish survey; and 3) a consumer workshop in Finland (N=8). The aim of the consumer research was to find out consumers attitudes towards different circular economy business models and circular products.

In total, 300 Finnish consumers responded to the survey, of which half were women and half were men. The average age of the respondents was 40 years (median 39). They lived in different parts of Finland. About two thirds lived alone or with a spouse and a quarter were families with children. The respondents were mainly full-time employees. Results available on-line: https://telaketju.turkuamk.fi/webinaarit/kuluttajien-suhtautuminen/.

The international respondents were recruited through the partner networks from European universities. We targeted the age group 20-29 that was also one of the age groups in the Finnish survey. In total, 57 consumers participated the in surveys: 33 from Germany, 15 from Sweden, five from the Netherlands, two from France, one from Switzerland and one from Austria. Due to the different number of participants from several countries, we decided to combine all of these results together and compare them with the Finnish results from the same age group. In this international study, 72% were women and 28% men. The average age of the respondents was 25 years. Almost half (46%) of the participants lived alone, 23% with a roommate, 18% with a spouse, 11% with their parents and 2% with a spouse and children. The respondents were mainly students (96%) and only 4% were full-time employees.

The participants of the workshop were mainly recruited via the Telaketju’s Instagram account. This is why the participants were more interested in textiles and textiles recycling compared to general population. The workshop was started with a presentation about the circular economy of textiles and demonstrations about different kinds of circular textiles by VTT experts. This workshop involved a total of 8 Finnish consumers from which five were women and three men. The average age of the respondents was 32 years. They lived in different parts of Finland. Three participants lived alone, three with a spouse and two with a spouse and children. Four of the respondents were unemployed or laid off, three worked part time, and one worked full time as an entrepreneur.

4 Sustainable Materials

This section contains summaries of several surveys related to materials, which we carried out during the project. These included bio-based solutions for textiles including both new bio-based fibre materials and bio-based chemicals for textile coloration and finishing (Chapter 4.1) and commercial availability of sustainable materials (Chapter 4.2). In case of recycled materials we firstly reviewed Certificates and Labels and secondly the availability of recycling technologies and recycled fibres (Chapter 4.3). Furthermore, also textiles and source of micro plastics was also reviewed (Chapter 4.4).

4.1 Bio-Based Solutions for Textiles

Humans have cloth themselves using natural materials for millennia, but this has changed within past century. Currently over half of textile fibres produced are made of synthetics raw materials (Textile Exchange, 2020), and also textile production uses lots of chemical substances (Slater, 2003) - many of these chemicals are also fossil based. Sustainability issues including, for example, interest in returning to bio-based fibres, and other raw materials and chemicals, have been raised recently due to the high environmental impact of textile production.

Chemicals are used e.g. in textile dyeing and printing, and finishing treatments and in laundry and textile maintenance processes. Enzymatic processes for the pre-treatment and finishing of natural fibres is relatively widely applied in textile production, multiple enzymes are commercially available and development and optimization enzymatic treatments are on-going (Eid & Ibrahim, 2021). Enzymes are used, for example, for the desizing, scouring, bleaching and polishing of natural textile materials.

The most important factors indentified by our consortium for new chemical solutions are listed in Table 3. Bio-based origin belongs to this listing, among others. Within Telaketju literature surveys, the focus was set to new bio-based fibres, bio-based dyeing chemicals, including both dyes/colorants and dyeing additives, bio-based finishing agents, especially flame retardant, soil resistance and antimicrobial agents, and bio-based polymers in coatings.

Table 3 Critical factors affecting use of new chemical in textile production

Theme	Factors	
Technical and performance	Technical properties	Multifunctionality
	Durability	Suitanability for recycling
Safety and sustainability	Safety for environment	Safety for human
	Biodegradability	Bio-based origin
Regulation	REACH	Öko-tex 100
Economical feasility	Price	Availability

Bio-Based Fibres

Currently, more than 60% of the world's textile fibres are based on fossil raw materials. There is a need in textile fibre production to find alternative materials that reduce dependence on the fossil raw material base. Synthetic man-made fibres, such as polyester and polyamide, are made from fossil raw materials. On the other hand, natural fibres, such as the well-known cotton and wool, are bio-based and biodegradable.

Commercial bio-synthetic fibres are made from either partially or completely bio-based raw materials obtained from crops. PLA-fibres (a bio-polyester) are usually made from starch and bio-polyamide from castor oil. The crop-based bio-synthetics are the first generation of bio-based man-made fibres. For the second-generation bio-based man-made fibres, the raw material base expands to various by-products, such as agricultural and forestry waste and biotechnological raw materials produced by algae, fungi and bacteria. An example of a second-generation bio-based polymer is polyhydroxyalkanoate (PHA), which is formed, for example, by the decomposition of methane by bacteria.

In general, the greatest environmental benefit of bio-based raw materials is the transition from fossil to renewable raw materials. In addition, several studies have shown that bio-polymers are able to reduce the amount of greenhouse gases and prevent the depletion of fossil raw materials compared to controls made from fossil raw materials.

The environmental impact of cultivating a bio-polymer feedstock and converting it to a biopolymer feedstock is greater than that of the fossil comparator in several other environmental impact assessment categories. For example, fertilizers and pesticides used in the cultivation of the raw material increase the negative environmental impact of acidification and eutrophication.

In addition to bio-synthetics, the research in the field of man-made cellulose fibres is focusing on novel raw materials and novel solvents to produce more environmentally sound regenerated cellulose fibres. Novel and re-emerging plant and animal fibres are, for example, nettle, bamboo and opossum hair. In animal fibres, the research is focusing on the biosynthesis of recombinant proteins that could be used as sources of textile fibres, for example mimicking spider silk and hagfish slime fibres.

Bio-Based Chemicals in Textile Dyeing

Natural dyes come from renewable sources. They are often ecological, safe, non-carcinogenic, non-allergenic and biodegradable, and they may also have other functionalities such as antimicrobial and antifungal properties (Pinheiro *et al.*, 2019) or UV protection (Silva *et al.*, 2018). Bio-based colorants can be obtained from plants, mushrooms, lichen, algae, and also some microbes produce dyes (Räisänen *et al*., 2020). Many natural dyes have shown limited fastness properties and durability to washing, and, thus also processes and chemistry needs to be developed to overcome this drawback (Eid & Ibrahim, 2021).

In the process of natural dyeing, most often it is necessary to use a mordant for colour fixation. Mordants for natural dyes are typically metal based. Aluminium and iron are environmentally safe and have not been restricted by any eco-regulation. (Pinheiro *et al.*, 2019) Bio-based mordants, for example, tannins (Prabhu & Bhute, 2012), can also be used.

Alternatively, pre-treatments of material to be dyed are also an option for better fixation of natural dye (Gorjanc *et al.*, 2019). Examples from scientific literature about bio-based natural dyes and mordants (and other dyeing chemicals) are listed in Table 4. Commercial producers include, for example, Stony creek colors[4], Archroma[5] and Pili[6].

In addition to dye and mordant textile dyeing processes require surfactants, acids and bases for pH adjustment, and lots of water. In addition to the bio-based origin of dyes and mordants, more sustainable textile production should take advantages of new coloration processes reducing the environmental impact. Ethridge *et al.* (2018) have developed a new process based on ancient indigo dye and foam technology.

[4] https://stonycreekcolors.com/
[5] https://www.archroma.com/innovations/earth-colors-by-archroma
[6] https://www.pili.bio/

Table 4 Research examples of natural dyes and mordants for textiles

Chemical	**Origin and short description**	**Reference**
Dye	Indigo for cotton denim	Ethridge *et al.* 2018
	Bauhinia vahlii bark	Bar & Bar 2019
	Teak leaves (Tectona grandis)	Fiori et *al.* 2019
	Dyeing cotton with dye extracted from fallopia japonica leaves, cationic pretreatment used for better colour fixation	Gorjanc et *al.* 2019
	Curcuma longa, extract from Hibiscus rosa-sinensis, and Schinus terebinthifolius studied in dyeing of banana leaf fibres with bio-based mordant	Pinheiro et *al.* 2019
	Janothinobacterium lividum pigment, violaccin, studied to dye wool, wool blend and silk textiles	Heffernan & Deo 2019
	Pomegranate, madder, Gromwell, indigo, Eucalyptus leaves, turmeric and hard, and henna	Mentioned in review by Eid & Ibrahim, 2021
Mordant	Acacia mearnsii as mordant for plants based (see above) dyeing of banana leaf fibre	Pinheiro *et al.* 2019

Bio-Based Textile Finishing and Coating

Bio-based polymers and plant based bioactive materials are main groups for biomaterials use as textile finishing agents (Eid & Ibrahim, 2021). Bio-based polymers used in textile applications include chitosan, cyclodextrin, and sodium alginate (see Table 5). Bio-based substances have also been used in finishes from which the substance (e.g. probiotics[7]) is released overtime. Research examples related to bio-based finishes and coatings are listed in Table 6. Commercial producers include, at least, Devan[8].

Table 5 Possible uses of bio-polymers in textile finishing and coating, summary made from review by Eid & Ibrahim (2021)

Polymer	**Origin**	**Application areas**
Chitosan	Obtained from alkaline deacetylation of chitin	Antimicrobial, flame retardancy, aroma therapy, and multi-functional treatments with properties such as UV-protection, improvement of colour depth and shade, self -cleaning, resiliency, anti-crease
Cyclodextrin (CD)	Produced by the enzymatic degradation of starch	CD has the ability to host solid, liquid and gas compounds that can be released during textile use. It has been used e.g. for antimicrobial, UV protection, fragrance treatments.
Sodium alginate	Extracted from seaweeds	Antimicrobial finish, stabilizing agent for metal and metal oxide nanoparticle finishes

[7] Purotex® https://www.purotex.com/
[8] https://devan.net/ and https://fiberjournal.com/devan-chemicals-introduces-two-new-bio-based-textile-finishes/

Table 6 Research examples of possible bio-based finishing treatments and coatings for textiles

Finishing or coating	Short description	References
Flame retardancy	Phytic acid for cotton	Yu *et al.*, 2019
Flame retardancy	Tannic acid (from plant based tannins), phytic acid (naturally occ urring polyphosphate ester of inositol) and isosorbide (derived from starch)	Reviewed by Hobbs, 2019
Mould resistance, stability, UV protection, insect repellence	Extracts from plants, berries and trees	Studied in Future Bio-Arctic Design [9]
Bio-based polyurethane coating	Synthesis of PU from bio-derived material, such as vegetable oils, cashew nutshell liquid (CNSL), terpene, Eucalyptus tar, etc. for various materials	Reviewed by Noreen *et al.*, 2016

The results of the literature review of bio-based textile fibres are available as a blog post https://telaketju.turkuamk.fi/blogi/uusiutuvista-materiaaleista-tekstiilikuituja/; and as a survey https://telaketju.turkuamk.fi/uploads/2020/12/6b05eb88-biopohjaiset-kuidut-selvitys-draft.pdf; and of bio-based textile chemicals as a blog post https://telaketju.turkuamk.fi/blogi/biopohjaisia-ratkaisuja/ and as a survey https://telaketju.turkuamk.fi/uploads/2021/04/032adf3c-telaketju-2-bioratkaisut-tekstiileille-selvitys.pdf

4.2 Availability of Sustainable Clothing Textiles for Commercial Use

Designers and SME companies are showing interest in testing and utilizing new materials in their products, but they are facing challenges in finding producers of sustainable materials, trustable information, suitable minimum order quantities and other terms of deliveries for their needs. Higher prices of sustainable materials have been major obstacles in choosing them for commercial use. Fabric fairs are the most convenient forums to find the latest information. Especially micro companies are facing difficulties in meeting the minimum order quantities. End-of-rolls would be a satisfactory amount of fabric in many cases, but to meet the composition, colour, etc. requirements make it a challenging concept.

The recent development in the Polarstoff fabric fair selection showed that the demand for organic virgin and recycled clothing materials has increased. At the same time, the price difference between organic and non-organic has diminished being around 1.50-2.00 €/m more for organic depending on the case and total order. This difference in the material's price can be commercially tolerated if the price has previously been around 10.00 €/m. It is understandable, that if the price would be doubled, from 2.00 €/meter up to 4.00 €/m, it will affect the final price of the product dramatically but with a good sales argument. Mass and fast fashion companies like Lidl, Lindex and H&M are campaigning actively for the materials they are using in some of their articles. A higher price for more sustainable fabrics does not seem to be an obstacle.

Premiére Vision and Avantex fabric fairs in Paris offered a large international selection of materials including sustainable textiles out of which it is challenging to choose the trustable information and manufacturers. It was quite difficult to find a manufacturer who does not offer so called sustainable materials. Communication was somewhat wild and the best of them look very professional. However, the best way for a designer is to choose manufacturers and materials having audited labels or certificates (see Chapter 4.3.2). In marketing communication, the messages can be very misleading.

[9] Future Bio-Arctic Design (F.BAD) project, 2018-2021, ERDF https://www.luke.fi/en/projektit/f-bad/

Figure 28 Manufacturers provide information about the materials in multiple styles. From the designer's point of view only officially audited labels and certificates can be trusted. The first photo from the left indicates that the manufacturer can offer amfori BSCI [10] and Oeko-Tex[11], the second promotes animal rights by offering polyester based fake fur, the third manufacturer most likely has audited labels and certificates. Photo: Minna Cheung

Future Fabric Expo and C.L.A.S.S are virtual platforms offering materials selected according to their quality, innovation, and demonstrating an ongoing commitment to improved performance and reduced negative impact across the supply chain. Both platforms provided free (limited in Future Fabric Expo) access to their material bank where it is possible to use keywords such as a certain material category, manufacturer or certificate. Minimum order quantities varied depending on the material and manufacturer. C.L.A.S.S provides small swatches (18x17cm) for 0.99 € (price 4th May 2020). Common Objective CO is a platform offering information regarding fibres and fabrics as well as contacts to manufacturers of fabrics and products. Due to the lockdown and travel restrictions regarding the Covid.19 pandemic, fabric fairs such as Premiére Vision and Munich Fabric Start invested to develop their virtual services. These services will probably continue in the future when travelling and gathering are not restricted anymore.

As the information provided by the textile manufacturer varies and can be misleading, it causes difficulties in choosing the most sustainable materials. At the moment there still exists several unsolved issues regarding receiving trustable information. From the designer's point of view, certificates and labels provide the most trustable information and should be prioritized in the design process among other required features. It is also crucial for a designer, who is usually responsible in choosing materials, to update their knowledge about new material and recycling innovations. Constant education and information retrieval are needed, digital platforms should be further developed for better user-experience.

The purpose of this task was to study the availability of sustainable materials presented at fabric fairs for commercial use in order to support the designer in making sustainable choices. The study was carried out at Polarstoff, Premiére Vision, Avantex and ISPO international fairs during 2019. Fairs were mostly cancelled during 2020 due to the Covid-19 pandemic and moved onto the internet as virtual fairs. Virtual platforms were added to the study. Publication https://telaketju.turkuamk.fi/blogi/vastuullisten-materiaalien-saatavuudesta/

[10] https://www.amfori.org/content/amfori-bsci
[11] https://www.oeko-tex.com/en/

4.3 Recycled Raw Materials

4.3.1 Availability of Recycled Materials

Global textile markets were $599.8 billion in 2018 with an evaluated annual growth for the coming years of 9.5 % (The Business Research Company, 2019). The size of textile recycling markets is increasing its share. IMARC Group (2020) estimated that the global textile recycling market has been grown by 19 % annually between 2014-2019, and to reach a value of $5 billion in 2020, and continue with moderate growth. Allied Analytics LLP (2020) stated the market at 2018 as being $5.3 billion and estimated it to grow to $8.0 billion by 2026 with an annual growth rate of 5.2 %. Drivers for the change and increased demand of recycled materials include, for example, growing environmental consciousness, rapid depletion of raw materials, and an emerging trend of donated clothes (IMARC Group, 2020).

Global textile fibre production has increased from 107 million tons in 2018 to 111 million tons at 2019, with less than 20 % of those having some sort of sustainability credential (Textile Exchange, 2020). The Business Research Company (2019) suggest that textile manufacturers should consider invest especially in technologies enabling the recycling of post-consumer cotton into textile applications, while Allied Analytics LLP (2020) suggest that the highest growth in recycling can be seen with nylon (5.7 %), followed by polyester (4.9 %). Mechanical recycling (fibre recycling) is still a dominant method, while fibre raw materials recycling, such as chemical processes, are emerging and mostly still in pilot scales. Future developments are expected to focus on such chemical processes and, for example, the processing of material blends. (Fibersort, 2020a)

We reviewed 104 recyclers and/or producers of recycled textile materials with similar observation (Figure 22). Mechanical fibre recyclers can be found and mechanically recycled materials are available both in Europe and globally. We also found relatively many recyclers of synthetics. However, our listing also includes many companies providing textile fibres made, for example, from pre-consumer synthetics and from PET bottles, and these processes are mature and commercially available.

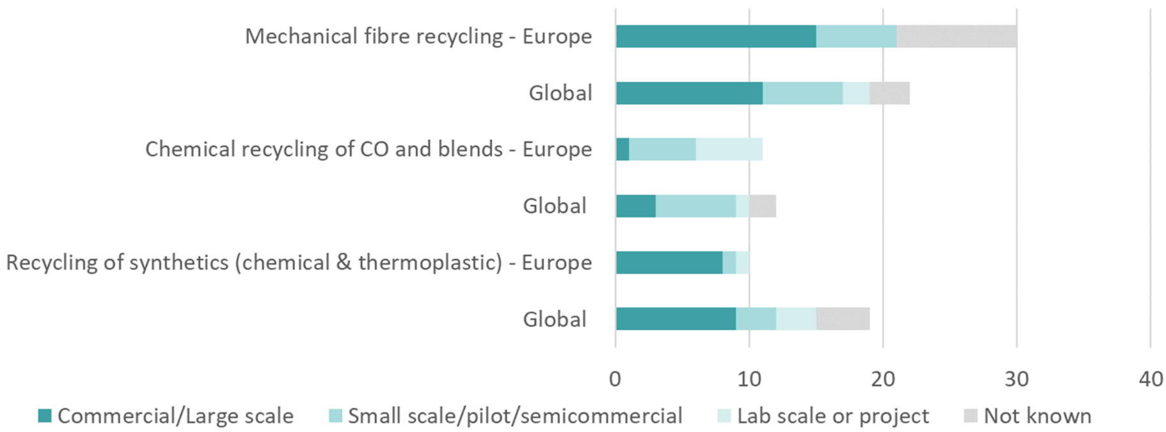

Figure 22 Overview of 104 recyclers/producers categorized by method and material, location and maturity/scale

Collection information of market reports and other materials containing information about recyclers and the availability of recycling technologies and recycled fibres. From these materials (or abstracts and news in case of reports with an access fee), we made an overall evaluation of the market situation. Three publicly available free reports (Fibersort, 2020b; Textile Exchange, 2020; Constantinou, 2020) were selected as main sources for the recyclers listing, where 104 actors were categorized based e.g. on recycling method materials, location, and maturity. Publication in Finnish is available via https://telaketju.turkuamk.fi/blogi/kierratysmateriaalien-markkinat-kasvussa/. Listing with some details of each actor has been published in English https://telaketju.turkuamk.fi/uploads/2021/05/cc03f9de-telaketju-recyclers-review-finished.pdf

4.3.2 Certificates and Labels for the Verification of Recycled Material Content

The purpose of certificates and labels for the verification of the amount of recycled input materials is to authenticate the origin of recycled material and monitor its flow in the production chain. The certificates can be used in the communication of the corporate image and to increase credibility and transparency through the production chain. Additionally, such labels can be used to meet the requirements of other actors in the value chain. These labels are voluntary and intended as a means of verification within the supply chain.

Verification of the amount of recycled material is based on an independent audit. There is currently no method by which recycled material can be experimentally distinguished from primary material. Many certificates use the definition of recycled material in accordance with ISO 14021: "*Material that has been reprocessed from recovered [reclaimed] material by means of a manufacturing process and made into a final product or into a component for incorporation into goods or services*". Recycled material content is calculated as the proportion, by mass, of recycled material in the mass of the product.

The labels and certificates for the verification of the amount of recycled material in the product are collected in Figure 23. The amount of the recycled material can vary and is often announced on the label. Recycled 100 Claim label is for products made from 100% recycled material. In addition, some eco-labels take into account the recycled material content as one of the criteria together with other aspects, such as social and environmental. Cradle-to-cradle certificate is based on the assumption that all materials are circulated in technical and biological loops. It is rather a designing tool than purely a tool indicating the recycled content. In addition to the recycled content labels, there are other labels for circular textiles, such as Upmade indicating the use of reused material and Blue Angel indicating the use of recycled plastics in fabrics.

Figure 23 Different labels and certificates grouped in four groups based on their intended use

A presentation about certificates was given within the Telaketju webinar series (in Finnish), and it is available on-line https://telaketju.turkuamk.fi/webinaarit/sertifikaatit-kierratysmateriaalisisallon-verifioimiseen/. The results are available https://telaketju.turkuamk.fi/uploads/2020/12/e9e1655f-sertifikaatit-selvitys.pdf

4.4 Textiles as a Source of Microplastics

There has not yet been one single definition developed for microplastics, which is why the definition varies between sources. For example, in the factsheet published by the EC, microplastic is defined as a plastic particle with a size between 0.0001-5 millimetres (JRC, 2017), but many earlier studies have also used as a definition of microplastic, a plastic particle smaller than one millimetre in size (Browne *et al.*, 2008; Costa *et al.*, 2010) According to one estimate microplastics cover 13.8 % of plastic emissions in the ocean surface layer (Koelmans *et al.*, 2017).

Microplastics are divided into primary and secondary microplastic (Venghaus & Barjenbruch, 2017). It has been estimated that even 35 % of the primary microplastics in the seas originate from the washing of synthetic textiles (Boucher & Friot, 2017). Oil-based synthetic fibres are considered to be a microplastic from textiles because of their synthetic origin (Setälä & Suikkanen, 2020).

Microfibres can be shed from textiles during production, processing, use and disposal (WRAP, 2019). All of these different stages of textile life cycle were dealt with in the report. It is important to pay attention to responsibility and durability already in the product design phase (Tikkanen, 2019) as this can have an impact on the release of microplastics during the later stages of the life cycle. Textile manufacturing is a very varied process to which used raw materials, as much as finishing processes, have an effect. Therefore, it is difficult to determine just one calculation that would measure microfibres during manufacturing. Nevertheless, during knitting and weaving, for example, the formation of synthetic fibres is easily noticeable, and it is estimated that the proportion of microfibres from the fibre fly is 52-98 %. (WRAP, 2019)

Use, washing and drying can release microfibres from the textile during the use phase. Microfibres can end up in the environment directly in the form of fibre dust, but it has been thought that the washing of textiles causes most of the environment´s microfibre emissions (Haap *et al.*, 2019). Microfibre emissions during after the use phase can form due to recycling, incineration of textile waste or landfill treatment (WRAP, 2019; Dris *et al.*, 2016; Henry *et al.*, 2018).

The lack of standardized preparation methods for microplastic samples makes it difficult to compare different microplastic studies to each other (Al-Azzawi *et al.*, 2020). The most important analytical methods in the studies reviewed for this report were filtration with subsequent microscopic analysis and/or gravimetric weighing.

The ways to reduce and prevent microfibre shedding from textiles have already been developed. The material choices are playing a great role in microplastic emissions; higher twist value, longer fibre and higher fabric density reduce the amount of microfibre released during the washing (Plastic Soup Foundation, 2017). Reducing the brushing of synthetic textile and favouring ultrasound or laser cutting, instead of cutting with scissors, can work as good mitigation methods in the production stage (Roos *et al.*, 2017; Cai *et al.*, 2020). The risk of microfibre emissions can be reduced by removing microfibres already in the production stage (Roos *et al.*, 2017).

Mitigation methods for microplastic in the use phase are usually related to changes made in the washing of clothes, but many of the study results supporting these methods are contradictory which makes it difficult to compare and interpret the results. One possible method is to use a front-load washing machine. One study observed that the shedding of microfibre was lower when using the front-load machine instead of the top-load machine (Hartline *et al.*, 2016). Using a shorter wash cycle length and lower temperature may minimize the shedding of microfibre (WRAP, 2019), and the study made by Cotton *et al.* (2020) supports these ideas. It is possible to capture the microfibre released in the washing by using capture and filtration devices such as Guppy Friend or Cora Ball (WRAP, 2019).

Being a new field of science, microplastics from synthetic textiles urges for more studies. This report focused on synthetic textiles and microfibres shedding from them, but many studies pointed out the fact that natural fibres and fibres of animal origin can also cause some potential harm to the environment. This raises interest so maybe it would be necessary to study the environmental impact of non-synthetic fibres as well.

The purpose of this study was to collect information about textiles as a source of microplastics from literature. The aim was to make a coherent whole that would deal widely with the microplastic problem from the perspective of textiles. The topics of this study were microplastics in general, textiles and microplastics, microplastics at different stages of the textile life cycle, analytical methods and reduction and prevention of microplastics. A presentation about textile based microplastics was given within the Telaketju webinar series in Finnish, and it available on-line https://telaketju.turkuamk.fi/webinaarit/tekstiilit-mikromuovien-lahteen/

5 Circular Products

This section focuses on circular products. Chapter 5.1 focuses of product design aspects, and Chapter 5.2 focuses on the evaluation of the environmental impacts of materials choices.

5.1 Product Design

‘*Approximately 80% of the environmental impacts of the product are locked already at the design stage (Ellen MacArthur Foundation). The designer’s choices predict the impacts of the garment's entire lifecycle from producing the product to the use, re-use and disposal. In companies’ hectic everyday life, the design process usually goes automatically, but by deepening and evolving the design processes the efficiency and the actualization of circular economy can be increased.*

Of course, designers are not always able to effect on the choices that are made in the companies, but their role as the contributor of circular economy is essential. Holistic sustainability and circularity can only be achieved when the company’s strategy and actions are engaged to it. … With the right information, the designer can more easily balance the design choices for circular economy’. (Ruokamo & Uunimäki, 2021)

In the following sub chapters three different viewpoints of designing in circular economy, namely designing for longevity (5.1.1), for recyclability (5.1.2) and with a waste minimizing approach (5.1.3), studied in our project will be reviewed. As an outcome of this work a designer’s guideline has been published in Finnish.

From Autumn 2019 to Spring 2021, LAB University of Applied Sciences has surveyed the role of product design in circular economy of textiles and clothing in the Telaketju 2 project. The Designer’s Guideline for Circular Clothing Design summarizes these studies and aims to raise awareness of how large the impacts and possibilities of the designers’ actions are in the clothing industry. The publication works as a gambit towards circular clothing design and its processes. It gives designers encompassing information about textile recycling and how to reflect that information to the design processes with circularity benefitting strategies. In the end this guide provides the Designer’s Check list, in which designers can evaluate the possibilities and challenges in the field of circularity.

Link to Designers guideline is http://urn.fi/URN:ISBN:978-951-827-360-1 and other publications include e.g. https://telaketju.turkuamk.fi/webinaarit/kiertotalous-tuotesuunnittelun-nakokulmasta/, https://www.youtube.com/watch?v=AIGWmYE_jWA, https://telaketju.turkuamk.fi/uutiset-fi/vaatesuunnittelijoiden-poydalla/, https://telaketju.turkuamk.fi/blogi/muotoiluprosessi-osa-1/, and https://telaketju.turkuamk.fi/blogi/muotoiluprosessi-osa-2/

5.1.1 Design for Longevity

According to the waste hierarchy and circular economy model, designing for longevity should be the priority aim and result of each design and manufacturing process in general. Historically textile products can be considered to fulfil this aim until the 1980’s when a new business model of affordable prices and quick deliveries started to change radically the way we use and purchase clothes, causing the current problems regarding textile waste. Designing for longevity has been identified as the single largest opportunity to reduce the carbon, water and waste footprints of clothing. Extending the lifecycle of textiles has a significant impact on the climate impacts of the textile industry. The durability of a textile product is the most important feature among other features to create longevity. Durability can be defined as physical durability which considers design decisions aiming to create products that can resist damage and wear. Whereas, emotional durability covers issues like relevance and desirability to the consumer. Considering both aspects during the design process are equally important.

Today, the most highly used business model is based on a linear system where products are supposed to be used and replaced frequently depending on the product type or market segment. In general, a T-shirt is expected to have a shorter lifespan than a coat. Luxury, middle and specialized market products are expected to last longer than mass market or fast fashion products. However, in all segments the products are usually presented that ‘they have been designed to last’ or like H&M announces in their internet marketing: ”*H&M offers fashion and quality at the best price, sustainably*”[12]. As long as longevity is an undefined concept, there exists the possibility of continuing to produce textiles as before. Any producer of textile products is able to qualify the products as ‘the best quality for the money’. Ageing of the style is a widely used method in order to create continuous demand and replacement purchases even when the existing item is still wearable. Applying this strategy of affordable prices and quick delivery times, the fashion business has grown to the stage it is today, offering a significant amount of employment possibilities as well as tremendous ecological and ethical problems. The State of Fashion 2021 report (McKinsey, 2021) declares that 65% of consumers said that they plan to purchase more long-lasting, high-quality items.

A significant impact on how long individual items remain wearable is created at the product design stage. Designing for longevity is simple from a designer’s point of view. The ability to choose the best quality and the most durable fabrics and accessories, using the most qualified workmanship to manufacture timeless items for a purpose are included in designer’s expertise. However, in reality the final choices are done not by the designer alone but a group of salespeople and the consumer.

In order to change the system faster, it also requires a change in the attitudes towards owning. According to the international State of Fashion 2020 survey and report, only 12% of industry experts (35 of 290) picked the ‘end of ownership’ theme from among the three most important phenomena affecting business. Experts working in the industry still see lending and renting as one of the new business opportunities of the future in the transition from owned goods to using services. The operating model has not yet reached critical mass, and its significance will increase in the future (McKinsey 2020 in Cheung 2020, 90).

Renting, especially formal wear, has a long history but only recently have clothing and fashion companies have started to serve their customers directly with a renting service. For example, the Finnish label Vestiarium added the possibility to rent an item first and if the customer wants to keep it, the rent will be deducted from the price. The items offered for rent are selected from the main collection which means that those items been designed to be owned and worn by one person, and not to be shared.

Design assignment was put into practice in order to compare the differences in the design decisions when designing daywear for rental or for purchase. The biggest difference in requirements of the item for rent and ownership were related to the fit, such as perfect fit, suitability for different body shapes, easiness for adjustments, modifications and alterations, preferably without sewing as an extra cost. Similarities can be found in the appearance of the item. In both cases the look or style should be desirable to the customers. Timeless and classis items are more likely to be purchased when rented items should look different from the basic items.

The results showed that items designed for rental differ from the items meant for purchase, see Figure 24. As mentioned earlier, durability, both physical and emotional, are the key issues in designing for rental. From the consumer’s point of view, the cost of renting will remain the same regardless of the manufacturing costs of the item. Manufacturing costs directly affect to the shop price, which significantly affects buying decisions for private use. When the price for the customer remains the same, it offers possibilities for the designer to choose higher quality, in other words, more durable materials.

The current principles in the terms of renting include the renter’s responsibility for maintaining the product before returning it. This causes somewhat troubles for the renter and, done wrongly, might shorten the lifespan of the product. Easy care, non-wrinkle materials are recommended even though they may not be the most sustainable as such, see Figure 25. The materials chosen contain mostly 100%

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[12] https://hmgroup.com/about-us/h-m-group-at-a-glance/

polyester and 100% wool. Both qualities can be found recycled which would be a better choice than using virgin material. Both can be recycled when the products will be discarded.

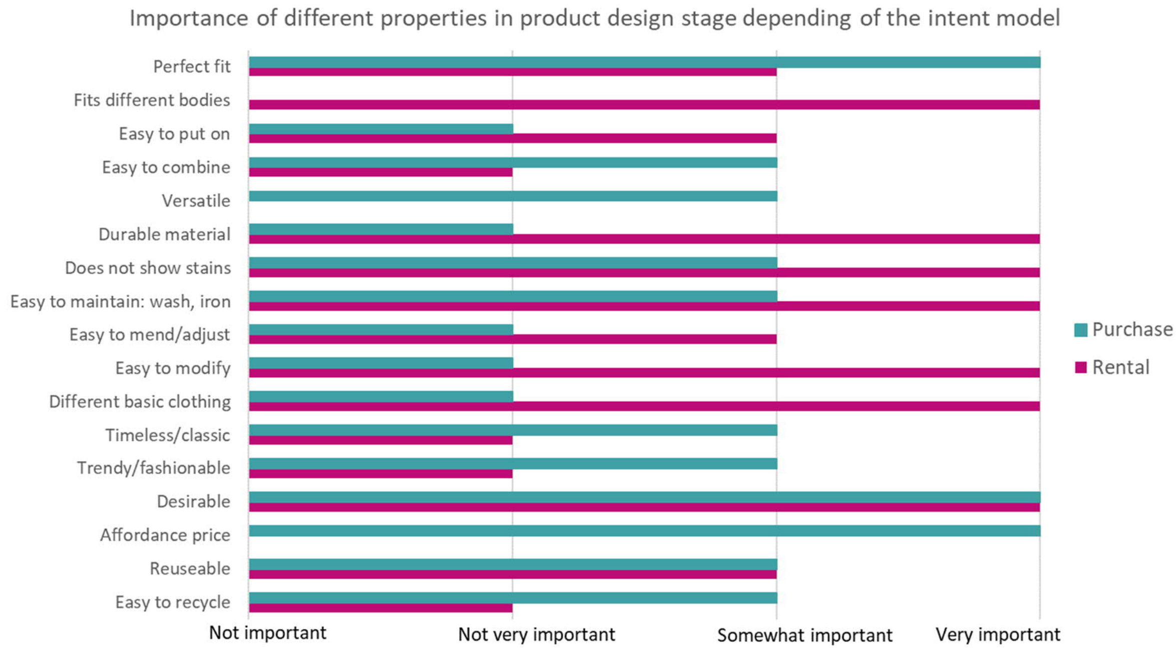

Figure 24 Differences and similarities in designing a product for purchase and rental.

Figure 25 LAB University of Applied Sciences' Wearable Design student Veera Laaksonen designed a capsule collection for rental. All items are easily adjustable and combined. They fit different bodies and are different from basic clothing

As mentioned earlier, clear care instructions are crucial in rental as the customer is supposed to return the item in good condition. Items made of such materials as wool require more information than, for example, cotton or polyester. For the same reason, products made out of these materials and mixed are preferable from the rental point of view. Polyester and polyester-cotton mixed material is easy to take care of and the material is very durable for continuous use. However, other kinds of products are also needed for the selection. Felted wool accessories like purses, bags and hats were considered interesting new items for rental, and we tested a possibility to protect wool material with bee wax (see details in box below).

The vulnerability of the wool felt cloth caused doubts and it was tested and developed by adding bee wax coating. Spreading was done to different types of hand felted samples by hand using liquid wax and a wax block. The aim of the test was to find a natural coating substance which would keep the look and touch of the hand felted wool felt cloth as authentic as possible. The hand felted cloth structure proved to be uneven and this natural feature made it more difficult to process than machine felt. The coating substance should be in liquid or spray form in order to submerge to the porous material. In addition, waxing changed the colour and touch of the felt, the process easily destroyed the felt cloth structure. Furthermore, the wax coating faded away during abrasion and might destroy other products, and it proved not to provide better abrasion resistance to the felt cloth. There remains the challenge in finding a solution to create a coating for wool felt cloth.

The proper use, storing and care of item is not familiar for many and this might shorten the product's lifespan. Product information in circular economy in general is covered more in Chapter 7.

Figure 26 LAB University of Applied Sciences' Wearable Design student Veera Konga designed care instructions for felted wool products for rental. The aim was to create clear, easily understandable and visually interesting instructions. It was noticed that generic instructions might cause misleading interpretations among users and shorten the lifespan of the item. Each product requires individual instructions

Items which are difficult to reuse and recycle with the current technologies like work wear and active wear should be designed for longevity. They often require mixed fibre textiles and special constructions in order to achieve better durability, care and safety properties than mono fibre textiles can offer. Work wear often also contains details such as embroidered company logos and the even user's name. Attention should be addressed to choosing the suitable materials and manufacturing methods for each purpose. Possible details should be removable, repairable and ductile. Work wear should also meet the demands of the user regarding comfort and appearance. According to the discussions conducted during the process the usual complaints about work wear concern these issues. No matter how long-lasting, sustainable and easy to reuse and recycle the product is, if it is not desirable it can be considered a waste of resources.

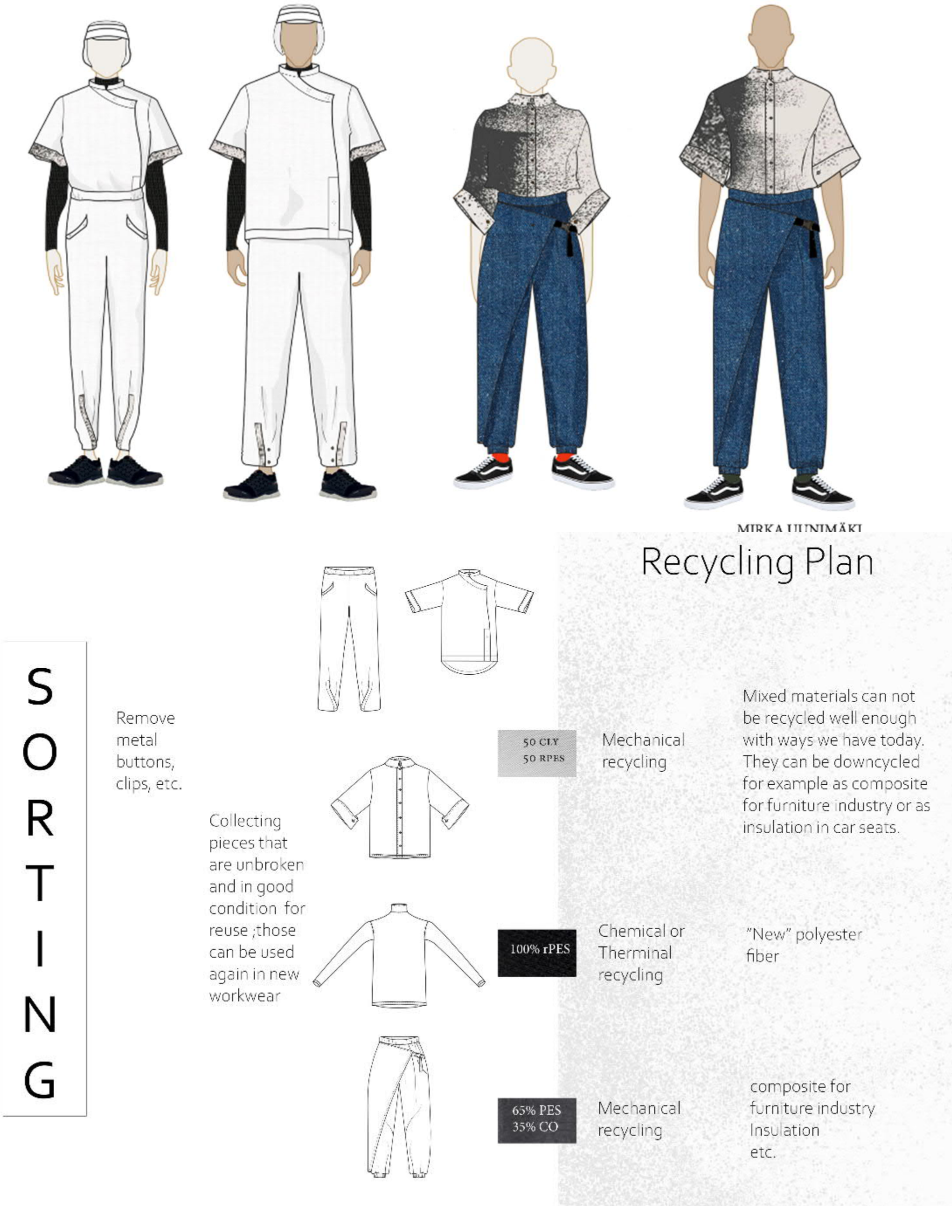

Figure 27 LAB Wearable Design student Mirka Uunimäki designed work wear for specialized food sector. The aim was to create more fashionable (desirable) yet long-lasting items. Besides the design recycling plan (lifecycle plan) was to be considered for each item

The quantity of items including technology (wearable technology, smart clothing, etc.) has been growing. Sensors and electric circuits have been added to wearable products for different reasons. LED-technology made it possible to create a new kind of work wear in which the technology brings value to the wearer by upgrading the safety properties. Adding light to one's outfit also has entertaining purposes. The results show that firstly, the battery needs to be small in terms of size and capacity. Secondly, the dispensable Li-Ion battery can be replaced with a reserve power bank, no need for an extra battery. Thirdly, technology should be removable and repairable. Fourthly, the item should be wearable without the technology. (Ahola, 2020)

Figure 28 LAB Wearable Design student Henna Ahola designed casual wear with LED-technology. The aim was to consider the conflicting demands of sustainability and e-textile in a single wearable product designed for longevity. Product photo: Annika Luukko. Device photo: Henna Ahola

Integrating technology into clothing requires solid arguments as it makes the items very difficult or impossible to re-use and recycle. Monitoring body functions is a good argument. At the moment, new more comfortable and trustable sensors and devices are being developed. They can be attached directly to the body, for example, a printed electric circuit on an elastic plaster. This development makes it unnecessary to integrate technology into textile until all parts are easily recyclable or biodegradable.

The purpose of this task was to examine the concept of design for longevity in literature and in practice by creating product concepts for various purposes; daywear for rental, work wear for specialized field and casual wear with electric components. In each concept, the founded properties are combined. The design concepts were created by the Wearable Design students at LAB.

5.1.2 Design for Cyclability

Whereas the traditional design process usually focuses mainly on the function and aesthetics, in a sustainable and circular design process a designer observes the whole life cycle of a product by considering all the steps during the product lifecycle. According to Ellen MacArthur Foundation, it is estimated that even 80% of the product's environmental impacts are locked at the design stage (Ellen MacArthur Foundation, 2020a).

Today's designers are required to understand the environmental, ethical and circular issues of the industry and implement the innovative solutions for a product's extended lifespan through design decisions. A designer must be aware of these requirements when designing the whole lifecycle of a product: design, materials, manufacturing, use, reuse and finally remanufacturing, recycle or disposal. At the same time, if aiming also for the sustainable design processes, a designer should also concentrate on the ethical and environmental issues around the product during its whole lifecycle.

In circular design, a designer should aim to design a product, which does not follow the linear model of *take-make-waste*, but which instead creates the ideal circumstances for the circular model to actualize. Circular design, at its best, can create new circular business models into use. For example, by choosing recyclable materials, designer can lead the way to the new circular service models, such as take-back or second-hand services.

One certain selection of materials is not over the others and therefore no material is unequivocally better than the other, when considering all the aspects from ethical and environmental point of view. Still, when aiming for cyclability, a designer should prefer the materials that are recyclable in current recycling systems, such as mono materials. Mono material strategy alone is still too weak a starting point for holistic circular design, since a designer must still consider the use over the other aspects. A designer must primarily design for a real need and for use. These aspects are the most relevant in circular design. A material choice is successful from both a circular and sustainable point of view only when it serves the use of the product and, finally, when the remanufacturing, recycling or reuse opportunities have realistic perspectives in the present or at least in the future.

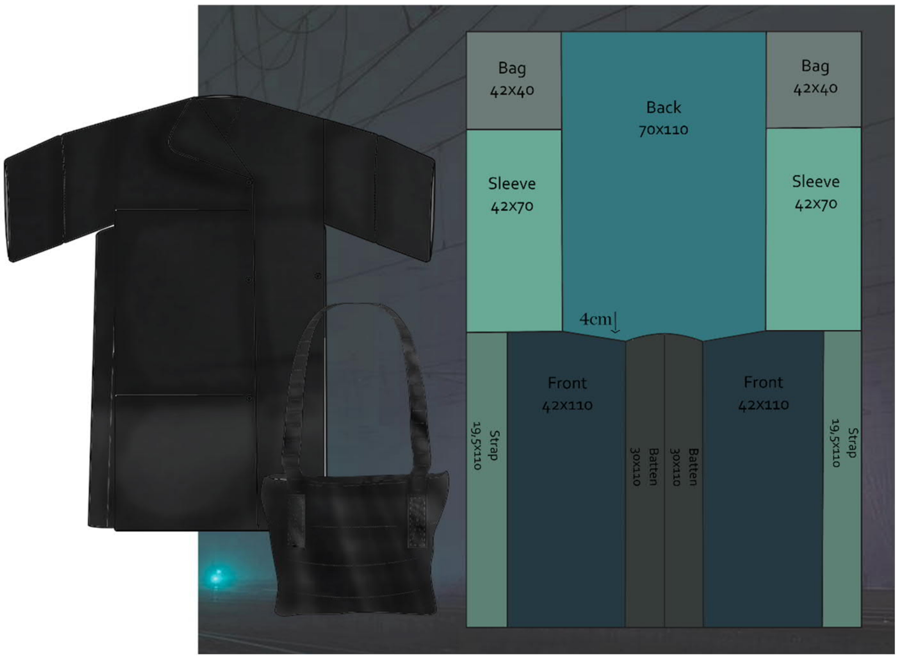

Figure 29 LAB Wearable Design student Mirka Uunimäki designed a winter jacket by using mono material and zero waste strategies. The jacket is designed to be easily recycled

In addition to understanding the material production processes, a designer should also understand the processes of recycling of both clothing and textiles. When it comes to clothing, the recycling process includes not only the main material (textile), but also the other components such as zippers, buttons, elastics and finishing's. Still the recyclability of the components is not enough. A designer must design for disassembly; the components need to be separated at the beginning of the recycling process. Circular design requires a lot of extensive expertise from the designer. One challenge is in the material availability of the sustainable and recyclable materials: in the most sustainable or circular material choices, the designer usually faces the commercial challenges.

Figure 30 The LAB University of Applied Sciences' Wearable Design student Hanna Vuorela designed a work wear outfit (on the left) out of recycled cotton-polyester blend. The material itself cannot be recycled, but the outfit was designed for disassembly and to be upcycled: the pattern pieces can be reconstructed as a new outfit (on the right)

The purpose of this task was to design different circular design concepts. The aim of these concepts was to survey and compare how different design and material choices effect the product's lifecycle and its recyclability. The design concepts were created with the Wearable Design students from LAB.

5.1.3 Design for Waste Minimization

Whereas it is important to design for cyclability, a designer needs to invent the ways in which to reduce waste in the first place. That can be done in several ways by using sustainable design strategies and by finding ways for waste utilization: recycled or remanufactured materials. In recycling process, the product is reduced all the way back to its basic materials by reprocessing. Finally, the materials are remanufactured or repurposed into new products (Ellen MacArthur Foundation, 2020b).

From an industrial point of view, a remanufactured product can level up in a higher hierarchy compared to the original one if the features are better than in the primary product. The main point of remanufacturing is to use discarded product or its parts in manufacturing a new product. The new products are pointed for the new users. (Karvonen *et al.*, 2015). Ellen MacArthur Foundation defines remanufacturing to consider the product or the parts of the product that are remanufactured into the same use (Ellen MacArthur Foundation, 2017c).

Upcycling is a category of remanufacturing. Alongside zero waste design, it can be considered as one of the sustainable design strategies that aim to waste minimization. In upcycling, the reused material comes from the used textiles such as curtains or other home textiles. Upcycling targets to the products that are either same valued or higher valued compared to the previous products (Redress Design Awards, 2019). The opposite term for upcycling is downcycling, which means that the old product reaching the end of its first use is remanufactured into a lower valued product. In the textile and clothing industry this kind of waste is usually the pre-consumer cutting waste caused at the beginning of clothing production. The waste is remanufactured into use for the car industry to become the lower valued material for insulations or oil rags. Also, when recycling the old polyester shirt back into yarn is considered as downcycling, since the yarn itself has a lower value than the garment.

Figure 31 The LAB Wearable Design student Beda Suni's collection uses discarded towels collected from hair salons. Stained towels are usually thrown away into mixed waste or, in some cases, given to the dog shelter homes. The towels are stained in use and their lifespan is usually rather short. Dye or Die collection was presented in PINNI magazine in Autumn 2020. Photographer: Kalle Kaltio

When aiming for waste minimization, the design process is slightly different compared to the traditional design process. One remarkable difference is that those methods (zero waste and upcycling) are not suitable for mass production because of the variations between different sizes. The material is a more essential leader in these processes than in the traditional one, since in these strategies. Availability and other features of the material are guiding the end result in an aesthetic and functional way, whereas in the traditional process, the product may end up with the same features even when made out by using different materials. Limitations can actually encourage a designer to end up with more innovative solutions.

The purpose of this task was to test different sustainable design strategies for waste minimization and waste utilization. The LAB Wearable Design students were using upcycling and zero waste design methods to recreate new products out of used materials. This was not just fixing, updating or maintaining the old textile products. The aim was to give a new extended lifecycle for an old textile product.

5.2 Environmental Impact of Material Choices

5.2.1 Comparison of LCA tools

The subject and purpose of comparison of LCA tools was to collect information, experience and observations of predefined tools that determine environmental impacts of textiles. The main preference was PEF, Product Environmental Footprint, developed in EU (Pesnel & Payet, 2019) and also book focusing on LCA (Muthu, 2015). The software and tools that were examined in this project were STJM's environmental impact calculator, Higg MSI, OpenLCA and GaBi.

Analysis considered, in particular, the following qualities: exploitation of PEF in results, using type of the counter, accessibility and reliability, operating costs, and the capability to compare the two different T-shirts (mechanically recycled cotton T-shirt and virgin cotton T-shirt). Analysis only considered the early phase of the product's lifecycle, ergo from raw material to store (cradle-to-gate).

The key result of the comparison was, that not all the environmental impact counter tools suit the lifecycle assessment because not all of them consider the requirements of PEF. Of the tested tools, Gabi and OpenLCA can be perceived to be a lifecycle assessment tool. STJM's environmental impact calculator is valid when there is a need to compare different materials. Higg MSI is suitable for comparison between different materials but it also provides information of the environmental impact of different manufacturing processes. However, it is not as inclusive as GaBi or OpenLCA. The main results are presented in Table 7.

Table 7 Comparison of four simplified LCA evaluation tool

	GaBi	OpenLCA	HIGG MSI	STJM
Suitable for comprehensive LCA analysis	X	X		
Considers requirements of PEF	X	X		
Number of considered environmental impacts of PEF	16/16	16/16	4/16	0/16

Besides environmental impact tools, also the social impact analysis method, namely social cost benefit analysis (SCBA), was also examined. SCBA is a method that tries to clarify the most accurate picture of the project or project under consideration. The objective of the SCBA is to determine as closely as possible the positive and negative impacts that the projects bring. These projects are often accompanied by the involvement of outside funders.

The analysis takes into account the costs of the investment and the direct benefits, such as profit, taxes and commissions. The calculations also consider social impacts such as factors affecting safety, travel, health, markets and laws, as well as the amount of emissions and environmental impacts. SCBA is not widely used in Finland. The analysis is very challenging and demanding to implement. The wide range of things to be considered makes analysis even more difficult.

A comparison of LCA tools was executed during the summer and autumn of 2020 as a student work. The results were presented first in the VBV-workshop October 2020 and afterwards as webinar in December 2020. The outcome included general knowledge of the counters, common principles and observations of the usage, customs of how the results were presented, the abilities to consider the guidelines of PEF in calculations and observations of the testers during the usage. A short review of PEF and how it should be taken into account in textile lifecycle assessment was also included in the outcome.

The early phase of the project companies suggest that the SCBA method could be lightly examined during the project. The survey was conducted as a literary review and presented in the VBV-workshop in October 2020.

5.2.2 LCA of T-shirt from Virgin and Recycled Fibres

The aim of the study was to determine the environmental impact of a T-shirt produced in two different ways by using life cycle analysis (LCA). The scope for this Inventory was from cradle to gate. The use, possible repair, recycling, and disposal of the T-shirt are disregarded in the calculation. One T-shirt is made from recycled cotton by open-end spinning and the other from virgin cotton. The purpose of the comparison is to find out how much environmental impact can be reduced by making the product from recycled material and which steps consume the most natural resources.

An example of a T-shirt made from recycled cotton was a Pure Waste L-sized shirt (weight 200g) made from 60% recycled cotton and 40% recycled polyester made from plastic bottles. At the beginning of a shirt's life cycle, when recycled cotton is torn back into fibre, the length of the fibre is shortened, making its durability suffer. Polyester is added to this mixture to spin a resistant yarn. In the future, however, efforts will be made to change this relationship.

Preliminary results suggested that a 200 g recycled cotton T-shirt would emit a total of 1.165 kg of greenhouse gas emissions (CO_2-Eq). The virgin shirt process emits 2 kg of greenhouse gasses, which means that the number of emissions from the process of a shirt made from recycled cotton would be about 0.84 kg less.

The biggest differences were reflected in water consumption. Production of a shirt made of virgin cotton consumes a total of about 1,400 litres of water, a large portion of which comes from the cultivation of cotton. Pure Waste does not dye their T-shirts at all, so the colour of the shirt is determined by the colour of the textile waste. In this case, water is consumed in the whole process only in the finishing stage of the fabric. Pure Waste purifies its own wastewater, which meant, in calculations, that new water require in processes was 30% at maximum. In this case, the amount of new water was, thus, less than one litre (0.98 litres), which is less than 1 % that of a shirt made of virgin fibres.

This LCA comparison was carried out as a thesis work by Sonja Salminen/Turku UAS. The Ecoinvent library was used to calculate the environmental impact, which found out the amounts of electricity, water and detergent consumed at different stages of the T-shirt. In addition, it provided impact factors for the Indian electricity grid, for example. The calculations were made by determining the global warming potential, GWP, of each stage of T-shirt production (IPCC 2013 GWP 100a was used). Earlier studies and LCA data e.g. Niinimäki *et al.* (2020) and REMO BV (2020) have been used in this study. The shirt process has been verified from Pure waste, but the amount of electricity, detergent and thermal energy consumed has been obtained from Ecoinvent data. There was also some loss in production, but it was further processed, so emissions from it were not included.

The thesis has been published in http://urn.fi/URN:NBN:fi:amk-2021061415942

6 Recycling

This section focuses on recycling. Chapter 6.1 gives an overview of the national collection system for end-of-life textiles in Finland. Chapter 6.2 concentrates on sorting including studies on NIR identification, our ideas for the classification of textile waste different textile fractions, and also review of manual sorting in Finland. Chapter 6.3 shows an updated cost model for collecting sorting and recycling textile waste in Finland. And finally, a summary of demonstration activities carried out within research project as well as examples from company demonstrations, is given in Chapter 6.4.

6.1 National Collection of End-of-life Textiles in Finland

End-of-life textiles mean textiles that are discarded by their owners. Such textiles include both textile waste and reusable textile products. Unsorted post-consumer textiles from households are municipal waste. According to waste hierarchy, we should prevent waste from being generated and recover any waste whenever possible. If this is not possible, waste should be primarily reused or recycled as material and, secondarily, recovered as energy at waste incineration plants. In Finland, we do not place municipal waste in landfills.

In order to arrange the national collection of end-of-life textiles, all municipal waste management companies are needed to participate in and arrange the collection and pre-sorting in their own operating areas. In Finland, we have around 30 waste management companies owned by municipalities and those covers the whole Finland. For successful collection and pre-sorting, we need extensive cooperation and a variety of action models. Our objective is to have the collection system ready in 2023. Already during 2020 the collaboration agreement was signed between five companies and the collection and local pre-sorting has started in those areas.

Third sector operators, such as charity organisations, have collected textiles for reuse already for years. However, these collections should not be confused with the collection of end-of-life textiles. The residents are instructed to primarily deliver reusables to charity organisations. Collaboration will be done with organisations which already have extensive knowledge in sorting and infrastructure for collection. End-of-life textile collection should support the existing systems, not hinder them.

End-of-life textiles can be collected in many different ways and methods. Experience with different methods has been gained from:

- a covered skip in sorting stations,
- waste bins that hold 660 litres in smaller sorting stations,
- metal textile collection bins,
- and a deep collection container (used in Rauma).

The Finnish weather is challenging, and it must make sure that moisture does not ruin the materials in collection bins, during transportation or in a storage. Because textiles are easily perishable, the companies should pre-sort them near the collection place as quickly as possible. This is also why first stage pre-sorting must be completed before sending the textiles to the processing plant. In this way, we can avoid unnecessary transport and minimize textile spoilage during transport and storage. Through sorting, we wish to guarantee the high quality of the raw material. Sorting is divided into four stages and each municipal waste management company can select one that is suitable for them. More details about the stages and videos for sorting instructions have been made available.

Also, to bring the collection closer to the citizens, to get the collection indoors and to engage large network to the national model, LSJH is piloting supplementary collections, KaMu collection, at shopping centres, clothing stores, and second-hand markets. The pilot will be held during 2021 and the goal is to scale it up to the whole Finland if it works well.

Figure 32 Covered skip used in LSJH's sorting stations

During the Telaketju project, a report about national collection and sorting was published (LSJH, 2020). The publication goes through the reasons why it is important to have national harmonisation and priorisation for the collection, how and when this collection will be carried out, and how the various operators will participate in the collection.

The report is available online https://telaketju.turkuamk.fi/uploads/2020/08/0c08d295-national-collection-of-end-of-life-textiles-in-finland_lsjh.pdf and presented in https://www.youtube.com/watch?v=3GwtRKBVTjs In addition, detailed instructions for manual sorting including links to videos can be found in Finnish and English via LSJH website https://poistotekstiili.lsjh.fi/poistotekstiilin-kerays-ja-lajittelu/

6.2 Sorting

6.2.1 Identification of Textiles

Near infra-red spectroscopy (NIRS) is used to identify fibre materials of textiles on an industrial scale, for example, in Fibersort by Valvan[13] and Siptex lines (IVL, 2019). The reliability and capabilities of NIRS have been studied during the Telaketju and Telaketju 2 projects (Cura *et al.*, 2021; Cura & Rintala, 2019). With NIRS, it is possible to identify only the surface material as the energy of the light source in NIRS does not penetrate deep into the sample. The measurement is carried out from an arbitrary measurement point of a textile sample and gives an average spectrum of a textile sample composition.

Identification of most monomaterials samples can be done reliably, since their molecular structures are unique. Cellulose containing fibres have some exceptions. While cotton and viscose can be differentiated, since viscose is regenerated during spinning, there can be difficulties with the differentiation of cotton and lines as in both cellulose molecules are in their original state. When it comes to blended materials, more limits of the identification methods arise. Hyperspectral imaging may resolve most of the current problems, but these have their own limits, most notably a relative slowness compared to current NIRS methods. Where NIRS identifies an area, a hyperspectral camera would identify the pixels within it (Mäkelä *et al*, 2020). These are different methods for identifying the fibre composition of the area even though both operate at the near infra-red wavelength range. In the future, hyperspectral imaging could result in a more accurate determination of blend ratio estimation compared to NIRS.

NIRS measures an average spectrum of an area and essentially sees the structure of the sample as homogenous, even when it is not. This means that no matter if the sample is a mono material or a blend, only one spectrum is acquired. This may cause limitations to how well NIRS can differentiate blended materials, based on how the materials are presented on the surface. Our earlier work has shown that using REISKAtex textile identification and the sorting lab pilot at LAB at least 3% or more of the

[13] http://www.valvan.com/products/equipment-for-used-clothing-wipers/sorting-equipment/fibersort

blended material needs to be on the surface for current identification methods with NIRS to reliably disqualify samples as monomaterials out of heterogenous feed. Thus, for example, elastane in most cases remains undetected even if it is visible. The limit is based on allowing an error margin to the identification method. Blended material can be separated from monomaterial feed and from each other if the blend ratio difference is high enough. Blends containing more than ~3% of other material than the main component can be reliably disqualified from monomaterial categories. LAB's method currently remains inaccurate in differentiating between blended materials at ratios like 65% polyester (PES) / 35% cotton (CO) and 50% PES/50% CO.

Studies with elastane containing textiles

Being a surface reading measurement, it is unlikely that NIRS will identify elastane within samples, especially in low weight content, less than 5 wt%. This is due to the fact that elastane is implemented to textiles beneath the surface, either into the core of yarns or within the weave or knit. However, using REISKAtex's identification method, preliminary results indicate that a very high (above 10 wt%) elastane content in samples is enough to cause sample disqualification from monomaterial categories. In other words, even if elastane cannot be identified it causes such a disturbance to a measured spectrum that it does not match with a reference spectrum of any monomaterials. This allows a separation of pure monomaterial fraction from a textile waste stream containing elastane.

When identifying materials of high elastane content, it was observed that 10% elastane (EA) resulted in a "No Match" result caused by high ambiguity, *i.e.* a situation where the sample is identified to too many categories at the same time. In this case, polyamide (PA) containing ~10% EA samples are not clearly distinguishable from pure PA and 5% EA/95% PA samples, just as is the case with non-identified PA samples containing 20% EA. PA samples containing 20% EA results in correct categorization in approximately 38% of cases. The ambiguity of the sample increases with the blend ratio bias, this is the case with any blended materials.

Cotton 100% and cotton with <5% EA have too similar spectra to be separable with the current method that allows a certain error margin to monomaterial categories. In a study with samples containing <5% EA, a high ambiguity with 100% cotton and the blends is observed. The mathematical difference of the spectra is neglectable and when, for example, 3% EA content samples are compared to 100% CO library, this causes non-differentiating results and the sample is identified as 100% CO. The spectral differences could be higher if the EA were visible on the surface.

Identification results comparisons of two NIRS devices: REISKAtex and NIRONE

The wavelengths used of REISKAtex and NIRONE differ from each other slightly, 1100-1650 nm and 1550-1950 nm, respectively. In fact, the identification methods caused by a non-transparent classification method of NIRONE may also differ, which has an effect on the capability comparisons. For elastane identification, the wavelength range difference has no effect. The current method of REISKAtex tends to be less prone to categorise blended samples. The method's threshold for blends identification may have been set so high that it does not allow variations in blend composition.

Altogether 29 samples were measured and compared: methods agreed on 45% of cases and did not identify 21% of the samples to any category. NIRONE classified 21% of samples that REISKAtex did not, mostly PES/CO blends. It must be emphasised that NIRONE's CO/PES blend's classification is for 35% CO/65% PES composition only, and there is no detailed information on the threshold limits. REISKAtex has classes of 35% CO/65% PES, 50% CO/50% PES and 65% CO/35% PES, and the thresholds between these three classes have been set fairly small. Therefore, a direct comparison of these two NIRS devices is not entirely possible. In addition, REISKAtex identified 10% samples that NIRONE classified as unknown or falsely.

For all of the cases where NIRONE identifies samples while REISKAtex did not, the sample was a cotton-polyester blend. Apart from one sample measured, all the other samples that REISKAtex identified while NIRONE did not, were monomaterials. The REISKAtex method has been expanded with a silk library, which is why there was an extra identification biased towards it, as NIRONE's identification method did not covered silk.

All in all, it seemed that NIRONE has more positive identifications, partially due to assumed differences in the recognition algorithm compared to REISKAtex and partially due to the smaller observed area. The CO/PES identification differences especially seemed to stem from the threshold difference. The operating wave range did not seem to affect the identification quality. The identification method for textile fibre materials was possible with surface reading, but the surface reading nature of such methods may limit applicability.

Differentiating knit and weave structures using machine vision

In experiments to automatically differentiate knit and weave structures, the classification methods and algorithms proved to be more important than the technical equipment. Good results of over 99 % precision were achieved with neural network-based machine learning image recognition even using low-resolution cameras, while the software included in high-resolution smart cameras with machine vision systems was not sufficient for recognising the heterogenic textile structures. The summary of studies that have been carried out in Telaketju2 have been collated in Table 8.

Table 8 NIRS and machine vision studies that were carried out during the project

Study	Need and aim	What was accomplished	Observations
Low vs. high elastane content	Can elastane be observed in samples at different amounts?	Samples with different amounts of elastane were studied	Elastane is extremely hard to observe with surface reading methods
Pillow contents	Pillow paddings consist of different PES fibres; does the structure affect material identification	Pillow paddings of different fibre structures and covers were studied with NIRONE and REISKAtex	PES padding structure does not affect identification capabilities within the wavelengths used
Machine vision	Determination of colour and differentiation of knit and weft structures	Data for weave versus knit structure differentiation with machine vision algorithms were collected	Knit and weave structures are separable with machine vision systems
Cotton-polyester blends	How accurately different blend amounts are separable?	Research ongoing, more samples are needed to get a comprehensive conclusion of CO/PES blends of different composition	It seems that differentiating blends with over 15% content difference is possible. Current accuracy needs further study.
Linen separation from other cellulose based materials	Can linen be differentiated from other cellulose (cotton, viscose)?	Samples collected and studies carried out using REISKAtex	Linen cannot be separated from cotton with REISKAtex
Polypropylene (PP)	Can PP be identified and do colours affect identification?	Only few PP textiles available for testing	Granulated PP can be identified, more textiles PP samples are needed to build an identification method

The NIRS studies were carried out by using two NIRS devices: 1) REISKAtex textile identification and sorting lab pilot at LAB, which is equipped with a NIRS Analyzer PRO Window Reflectance analyser from Metrohm Nordic Oy. Spectral libraries aka classifications were prepared at LAB using verified textile fibre samples, and using a 2nd derivative chemometric method and 2) the NIRONE portable NIR scanner from Spectral Engines where the spectral libraries were developed by the supplier. Summary of NIRS results is available in https://www.youtube.com/watch?v=hlQAuk7EW64&list=PLH6Y5d-7NfA_d9aSMqApkvC175nLy6qKS&index=3&t=46s Scientific publications include Cura K., Rintala N. (2019)

Using NIR technology to identify value in waste textile streams, Autex conference https://ojs.ugent.be/autex/article/view/11650, and Cura K., Rintala N., Kamppuri T., Saarimäki E., Heikkilä P. (2021) Textile Recognition and Sorting for Recycling at an Automated Line Using Near Infrared Spectroscopy, *Recycling* https://www.mdpi.com/2313-4321/6/1/11

Machine vision for textile structure classification was tested by mechanical engineering students in Turku UAS using Omron FQ2 smart camera simulator, Omron FH-SM21R and Sick VSPM 6F2113 smart camera systems with included software as well as taking photographs with the students' own equipment such as smartphone cameras and USB microscopes and using them as input for a machine learning programme built in Python (Keras library), Microsoft Custom Vision tool and TensorFlow-based Teachable Machine. The results from the latter were promising, for example Custom Vision taught with 502 pictures (220 knit, 282 weave) gave recognition results of approximately 99 % precision. More details in Finnish at https://telaketju.turkuamk.fi/tietoiskut/konenako-tekstiilien-rakenteen-tunnistuksessa/

6.2.2 Classification

The classification of discarded textiles concerns the whole chain from incoming material, where the classification is related to properties of textiles, to outgoing material from a recycling process, where the classification is related to the effects of the recycling process to the properties of material. Additionally, classification can be based on the specifications from the next user of the material.

In this case, the recycling process selected was the mechanical opening of textiles. The different properties to which the classes can be based is collected to Table 9. The properties collected in the two first rows have been discussed in Chapters 6.1 and 6.2.1. The others are discussed here further.

*Table 9 Identified properties of materials for classification. *Classes from manual sorting are determined in (LSJH, 2020)*

Classes / property	**Methodology**
Input textiles	
Classes for national collection of textiles* • clean • contaminated (smelly, moist, dirty etc.) • reusable textiles • suitability for mechanical recycling	Manual sorting
Material composition most important classes • 100% cotton • 100% polyester • 100% wool • cotton/polyester blends	Automated sorting reliable with lab line REISKAtex/LAB Sorting possible with NIROne handheld device. The classes for the cotton/polyester blends, from the automated identification point of view, are possible with a 15% content difference.
Colour	Colours can be identified with a spectrophotometers which is a known technology.
Structure	Textiles can be divided based on structure, imaging technology have been used to separate e.g. jeans from other textiles.
Mechanical opening	
Opening quality	Gravimetric manual method developed
Fibre length	Manual comb sorter method was proven to be possible Automated methods may be possible after separating opened fibres from the unopened fractions.
Mechanical properties of fibres	Standardized method
Colour	Decolourization and re-dying is possible
Cleanliness	Mechanically opened fibres can be disinfected for creation further processes, if needed
Chemicals	For a single chemical, there are test methods available, but more analytical work is needed to get an understanding on the possible harmful chemical residues in the opened fibres.

Opening quality: The opening quality had a clear effect on the ring spinning process (see demonstration in Chapter 6.4) Even though, the correlation was not linear it was obvious that unopened fragments had a pronounced effect on the yarn spinning process. In addition, the opening quality was observed in the composite demonstration. In the compaction, first step in the process, the unopened fragments went through the process quite well, although they had an effect on the appearance to some extent. When the mechanically opened fibres act as reinforcing fibres, it was possible to have unopened fragments in the matrix, but they had an effect on the strength of the injection moulded composite.

The opening quality was determined by manually picking the unopened fabric and yarn residues from the opened fibres. From the opened fibres, the fibre length distribution was determined by the *Comb sorter* method, Figure 33. It showed that a manual measurement of fibre length was possible, but slow. Processing of one sample took about three hours. The sample size was moderately small (0.2 g), which enabled a relatively quick analysis. However, due to the heterogeneity of the sample, the sample size may not be sufficient and more studies are needed. Rieter has reported that the amount of fibres opened can be determined with a Shirley Trash analyser, originally developed for the analysis of cotton fibres, i.e. the determination of linter and trash content in cotton fibres (Schwippl, 2020).

For further studies, for example, an imaging-based method to determine the opening quality may be developed. Samples from mechanically opened fibres capture on a transparent tape are shown in Figure 33. Imaging can be further developed so that the fibre length can be analysed from the same images.

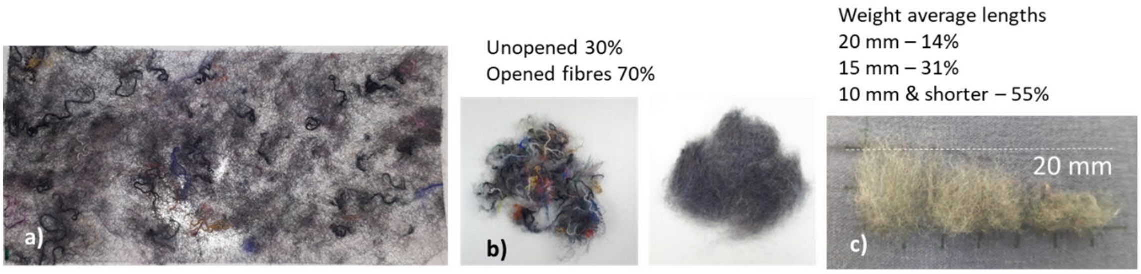

Figure 33 a) Mechanically opened fibres on tape: tape length of 10 cm and sample mass 0.3 g. Results from b) handpicked opening quality and c) fibre length distribution measured with Comb sorter method.

Fibre length: The fibre length is reduced in the mechanical opening process. Usually, yarn spinning is possible only when longer fibres are mixed with the mechanically opened fibres. This was the case in ring spinning demonstration (see Chapter 6.4.1), however, the yarn spinning demonstration confirmed that when the short and long fibre mix was optimized, ring spinning was possible.

From a mechanically opened fibre, it is possible to determine the fibre length distribution by the *Comb sorter* method, as long as the unopened fragments have first been removed from the sample. Possible yarn and fabric fragments clogged the combs and fibre length determination was not possible. The fibre length of virgin fibres can be determined by automated equipment, originally developed to determine the length distribution of cotton fibres. Equipment manufacturers state that these automated equipment are not suitable for recycled fibres, but if yarn residues have been removed from mechanically opened fibre, it may also be possible to use these equipment to determine the fibre length of mechanically opened fibre.

Mechanical properties: A standardized method for measuring the mechanical properties of fibres is available and the properties can be measured with special equipment. The standard fibre length for the measurement is 20 mm, in which case the total length of the fibre must be such that its ends can be attached between the jaws of the measuring device (25-30 mm). In some measuring devices, it is possible to use separate jaws for measuring short fibres, whereby the length of a fibre can be 10 mm. When measuring the mechanical properties of a fibre, the fineness of the fibre is always checked and, in order to measure it, the length of the fibre must be more than 25 mm.

Cleaning: In an industrial laundry, the thermal washing process to remove contaminants, such as micro-organisms, are typically carried out at 70°C. Alternatively, the temperature can be decreased and oxidative chemicals can be used to disinfect textiles. In general, such laundry processes are not feasible in textile recycling and the guidance in textile sorting is that contaminated textiles are discarded, preferably before collection. For certain specific applications, such as for medical textiles, a high cleanliness of material is required and the cleaning of fibres after mechanical opening is needed. VTT has demonstrated that the disinfection of mechanically opened fibres is possible (Heikkilä *et al.*, 2020).

Colour: Usually the colour of mixed mechanically opened fibres is greyish multicolour. It is possible to sort the textiles according to their colour. For example, cotton textiles with pale colours were hand sorted and after the mechanical opening the fibres were whitish compared to a batch that was sorted only based on the material, Figure 34. In textile dyeing, spectrophotometers have been used to analyse colours for decades. For textile sorting, the automated detection of colour is possible, but libraries need to be built with sufficiently wide tolerances so that the amounts of certain coloured textiles are sufficiently high. Other options are to remove colour with chemical treatments (Määttänen *et al.*, 2019) and re-dye the recycled material.

Figure 34 Effect on colour sorting on the colour of the mechanically opened fibres

For the determination of limit values for the properties of mechanically opened fibres for classification, a great deal more work is needed. Digitalization of the mechanical recycling process may accelerate the gathering of the understanding on the different relations between input material, process parameters and output material as well as suitability for further processing. When enough data is available and methodology is developed for the characterization of mechanically opened fibres, the classification can be translated towards standardization.

SFS Suomen Standardisoimisliitto is responsible for the standardization in Finland and the work is strongly linked to international standardization work. Now, SFS has one standardization group focusing on circularity, *SFS/SR 239 Kiertotalous* standardization group[14]. The group participates in the preparation of international standards for the circular economy. The work was started in 2018 and the aim is to develop models, tools, guidelines and requirements to support the transition to a circular economy and the achievement of sustainable development goals. The following standardization projects are underway: Framework and principles for the implementation of the circular economy; Guidance on circular economy business models and value chains; Measuring the circular economy, and Case study analysis: a performance-based approach to the circular economy. The Finnish group is following two international committees, Joint ISO/TC 207/SC 5 - ISO/TC 323 WG: Secondary materials; and ISO/TC

[14] Kiertotalouden standardoimisryhmä https://sfs.fi/osallistu-ja-vaikuta/standardisointiryhmat/kiertotalous/

323 Circular economy. In addition to ISO committees, CEN and CENLEC will continue strengthening the role of circularity in standardization in line with the European Commission's Circular Economy Action Plan[15]. One of the identified key value chains under circularity concerns textiles. However, in their work program for 2021[16], a standard for the recycling of textiles alone was not under preparation.

6.2.3 Manual Sorting

Manual sorting is one of the most employable phases in the post-consumer textiles value chain. Manual sorting is also the phase of the value chain, where subsidized work is mainly used. All organizations that do manual sorting in Telaketju and a few outside the network were invited to discuss and clarify the role of subsidized employees and the meaning of the work in society. They all gather the textile as a post-consumer textile or as donations, and they all have their own workshop or shop where they sell reusable textiles further. Almost 1/3 of the work is made by subsidized employees in the organizations. Basically, the manual handling phases are similar in all organizations that were involved. Phases are illustrated in Figure 35.

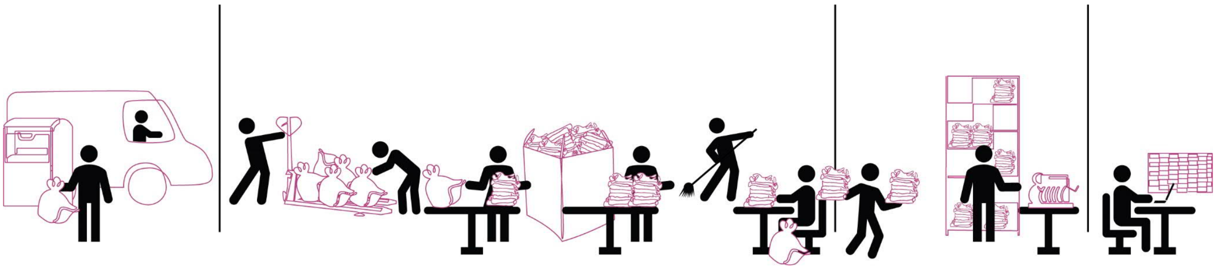

Figure 35 Phases of manual handling of collected textile donations: Collection - Transportation - Weighing - Raw sorting - Fine sorting - Logistics - Packaging - Pre-processing - Cleaning - Tasks in shop or workshop - Supervision

Our survey showed, that there are big differences in how much textile the employee can sort per day either the organization has long-term employees, or short-term, mostly subsidized, employees. In the organizations that have long-term employees one sorter can manually sort even 1600 kg of textiles in a day. In subsidized work, employees may have some social, physical or mental problems, and employment relationships are shorter, so employees do not have so much experience of the work. They may sort around 200-500 kg of textiles per day.

Manual sorting of textiles as a subsidized work was anyhow seen as very important for the employees and the benefits can affect the whole society. Work tasks are perceived to be meaningful and it has been a valuable step on the way to working life. Some phases are very simple, and a high knowledge and competence is needed at some phases. Different phases can still be done within the same organization and learned by doing. Many organizations also have, or plan to have, official education available for subsidized employees.

One task for sustainability work in Telaketju 2 was to clarify the value and possibilities of subsidized employees in the circular economy of textiles. The study was carried out with Telaketju organizations that carry out manual sorting with some additional actors. Besides meetings, information about manual sorting as a work was gathered as a survey from 4 associations, 1 utility company, 1 foundation and 2 municipal organizations. The results of this study has also been published as blog https://telaketju.turkuamk.fi/blogi/tekstiililajittelu-on-tyota-jolla-on-tarkoitus/

[15] Circular Economy Action Plan https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

[16] CEN CENLEC Work programme 2021 https://www.cencenelec.eu/news/publications/Publications/0953-WorkProgramme-2021_UK.pdf

6.3 Economics of Recycling in Finland

The economics of textile recycling was evaluated by modelling. The costs of the first phases of the textile recycling process, including collection, sorting alternatives, transportation and mechanical and chemical recycling were well mapped during the previous project (Hinkka *et al.*, 2019; Heikkilä *et al.*, 2019). The aim in the current work was to specify the costs in the pre-processing and recycling phase and to distribute the collected textiles into specified recycling processes and energy recovery. More specifically, updating the model was focused on dividing the materials into the most suitable recycling processes by including thermoplastic recycling, as well as energy recovery for materials that are not suitable for recycling (see Figure 36). Including the material division to recycling processes allows viewing the share of costs as a whole and in comparison to the other cost phases.

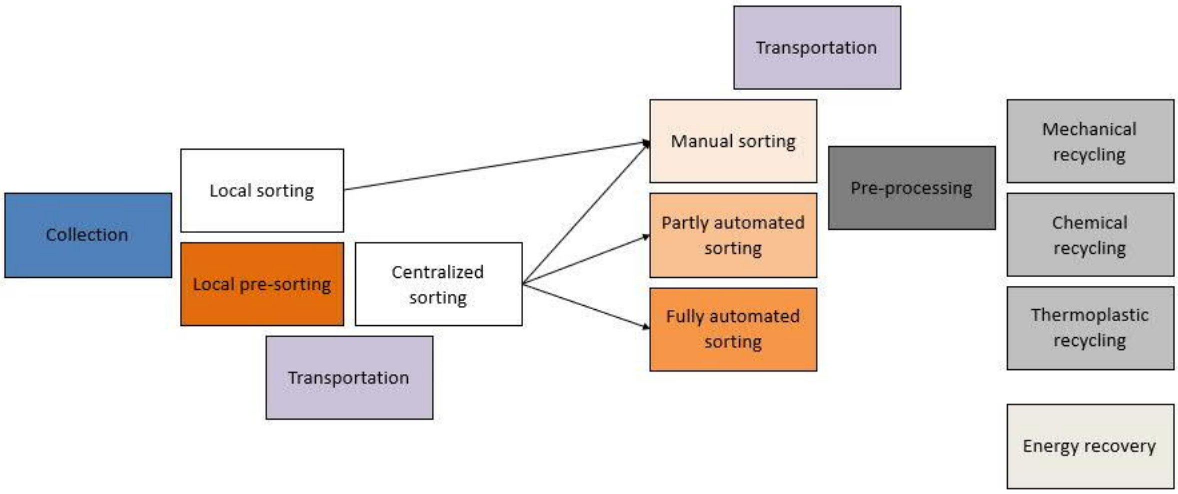

Figure 36 Phases and sorting alternatives of the model

6.3.1 Cost Modelling

Material fractions. The costs in the textile recycling model heavily rely on the amount of the collected textiles. It was assumed in the model that 4 kg of textiles per inhabitant would be collected, of which 20 % is separated from the pre-sorting phase: 10 % to energy recovery as not textiles or contaminated textiles and 10 % are estimated to be reusable. The rest was estimated to be sorted according to material fractions in the material sorting phase.

To know the costs of the recycling processes and energy recovery, there was a need to estimate the material fractions. These estimated fractions represent materials in sorting phase, when a pre-sorting phase is already conducted. It was estimated that most of the contaminated and non-textile materials (representing 10 % of total) and top quality reusable clothing (representing 10 % of total) are removed in the pre-sorting phase. Based on our earlier experiences and the literature, we expected that in Finland cotton (at 30 %) would form the largest single fraction from the rest, including textiles that may have small impurities and are therefore containing more than 95 % cotton (CO 95%+). Cotton-polyester (CO-PES) fraction were estimated to be 10 %. Contaminated, coated and laminated textiles were seen to be 20 % of the material sorting phase. The material fractions used in the model are presented in Figure 37.

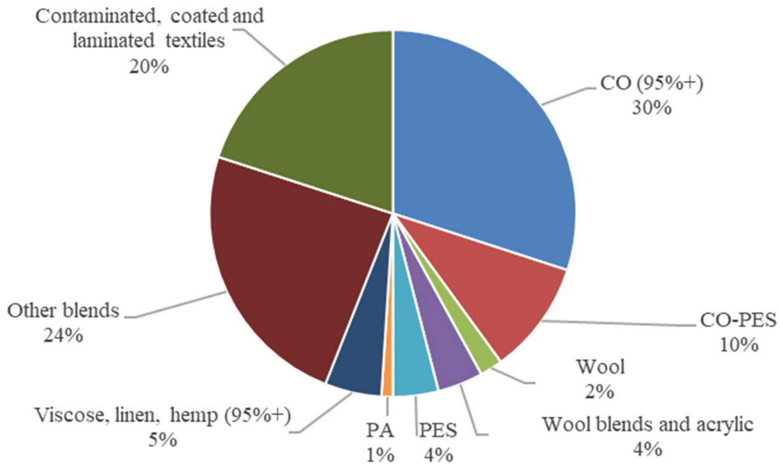

Figure 37 Material fractions for sorting in the model. CO = cotton, PES = polyester, PA = polyamide

Recycling processes and energy recovery. Table 10 presents the recycling processes for each fraction, that were identified based on estimates of optimal recycling processes and that would be available in Finland within a few years. The recycling processes included are mechanical recycling into fibres, chemical recycling of cotton and other cellulosic fibres (via dissolution) into fibres, thermoplastic recycling of synthetics (via melting) into composites and plastic products, and incineration i.e. energy recovery for textiles not suitable for recycling. Chemical and thermoplastic recycling of synthetics into fibres was discarded from the model, since it seemed improbable that it would be available in Finland in the near future.

Table 10 Material fractions and recycling processes in the model

Identified fraction	Sub fraction/ description	Assumed amount	Processing in model
Cotton (95%+)		15%	Mechanical recycling
		15%	Chemical recycling
Cotton-Polyester		5%	Mechanical recycling
		5%	Thermoplastic recycling: composites
Wool		2%	Mechanical recycling
Wool blends and acrylic		4%	Mechanical recycling
Polyester		4%	Thermoplastic recycling: plastic products
Polyamide		1%	Thermoplastic recycling: plastic products
Cellulosic fibres other than cotton	Viscose, linen, hemp (95%+)	4%	Chemical recycling
	Linen, hemp (95%+)	1%	Mechanical recycling
Other blends	No elastane	12%	Mechanical recycling
	High in polyolefins, no elastane	6%	Thermoplastic recycling: composites
	Complicated incl. olefins & elastane	6%	Incineration: energy recovery
Not recyclable	Contaminated, coated and laminated textiles	20%	Incineration: energy recovery

Figure 38 illustrates the division of the textiles to the different recycling processes and incineration from the material sorting phase. Mechanical recycling counts for the largest percentage from the material sorting phase, but incineration (energy recovery) also has a relatively large percentage.

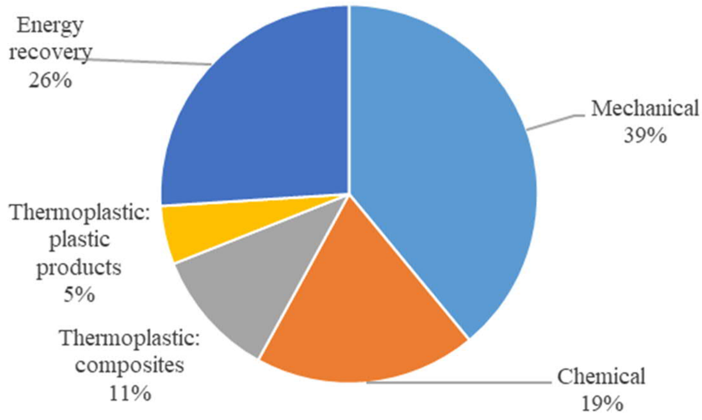

Figure 38 Share of recycling processes and energy recovery

6.3.2 Costs of Recycling Processes

Table 11 presents the costs of the recycling processes and energy recovery calculated by modelling the costs of these processes.

Table 11 Calculated costs of recycling processes and incineration

Process	Cost €/kg
Pre-processing	0.3 – 0.42
Mechanical recycling	0.22
Chemical recycling	0.65
Thermoplastic recycling to composites	1.22
Thermoplastic recycling to plastic products	1.07
Energy recovery	0.09

Mechanical pre-processing including the removal of hard pieces such as buttons or zippers estimated to cost 0.10 €/kg, and cutting and tearing, costing 0.20-0.32 €/kg depending on the producer of the system. The cost of the mechanical pre-processing is therefore 0.30-0.42 €/kg. The first alternative is used for the calculations of the model.

Mechanical recycling. The amount of the collected and sorted textiles for mechanical recycling from the material sorting phase is 39 %, which is approximately 6 800 tons. With the estimated amounts of collected material in Finland and recycled mechanically, the utilization rate of the recycling system would be approximately 80 % and the cost for the mechanical recycling or more specifically the *fine opening* is 0.22 €/kg.

Chemical recycling. We assumed that 19 % of the textiles would be recycled chemically, which counts for 3 300 tons. Our calculations suggest that, there is a need for additional material for the chemical recycling process, as the collected textiles in Finland are not sufficient for covering the costs of the recycling process as the utilization rate would be 20 % of the system. When material is added until the utilization rate is approximately 80 % the cost is 0.65 €/kg. The additional material added to the model was 10 500 tons. This could be sold as a service for imported textiles, but was added to the model as additional material without profit to decrease the cost.

Thermoplastic recycling. The thermoplastic recycling includes processes both for composites and plastic products as end products. Investment costs are not included for thermoplastic recycling, as it is estimated that there are enough existing processes for these in Finland. Altogether, the textiles from the material sorting phase to thermoplastic recycling are 16 %, but are divided further to processes for composites and plastic products as end products.

Thermoplastic recycling to composites. We assumed that 11 % of the textiles would be recycled thermoplastically to composites, which is equal to1 900 tons. The end cost for the thermoplastic recycling of the textiles depends on the quality of the recycled plastic to be used as a binder with the textile fibres. The binding material added to the composite is suggested to be recycled plastics, and the cost of the recycled plastic may be higher if a better quality of end material is desired, depending on the application of the material and its quality requirements. The cost for the recycled plastics was calculated to be 1 €/kg and it would be added as an amount of 60 % of the mix. The calculations also include a compounding cost of 0.60 €/kg, as well as energy consumption of 0.07 €/kWh and 0.35 kWh/kg. With these calculations, the end cost of this process is 1.22 €/kg, as in Table 11. If the recycled plastics would be of a higher quality and cost 1.5 €/kg, the cost for the end material would be 1.52 €/kg.

Thermoplastic recycling to plastic products. We assumed that 5 % of the textiles would be recycled by thermoplastic recycling to plastic products, which is 880 tons. For the thermoplastic recycling of textiles to plastic products, it was seen that virgin plastics should be added for improved quality of the plastic products, as the quality would not be sufficient for use in plastic products if only textiles were used as a raw material for plastics. This increases the costs, but with improved possibilities for end use it was seen as a necessary addition, as it would not otherwise suit most products. The costs include adding virgin plastics, assumed to cost 1.50 €/kg, of an amount of 30 %. It also includes costs for compounding, which is estimated to be 0.60 €/kg. Finally, it includes the energy consumption of the process, which is assumed to cost 0.07 €/kWh and that the energy consumption is 0.35 kWh/kg. The cost of this process is calculated as 1.07 €/kg as presented in Table 11. Another alternative would be to add chemicals for chemical rehabilitation, costing 0.15 €/kg.

Energy recovery. Energy recovery from incineration is process for textiles, that are contaminated or cannot be recycled with the available options. The cost for incineration for energy recovery is 90 €/ton or 0.09 €/kg. It is estimated that 26 % or 4 600 tons of the textiles from the material sorting phase would be incinerated. In addition, it is estimated that 10 % of the textiles in the pre-sorting phase would be separated for incineration, but this cost is calculated in the costs for the pre-sorting phase. Figure 39 illustrates the cost distribution of the different recycling processes and energy recovery.

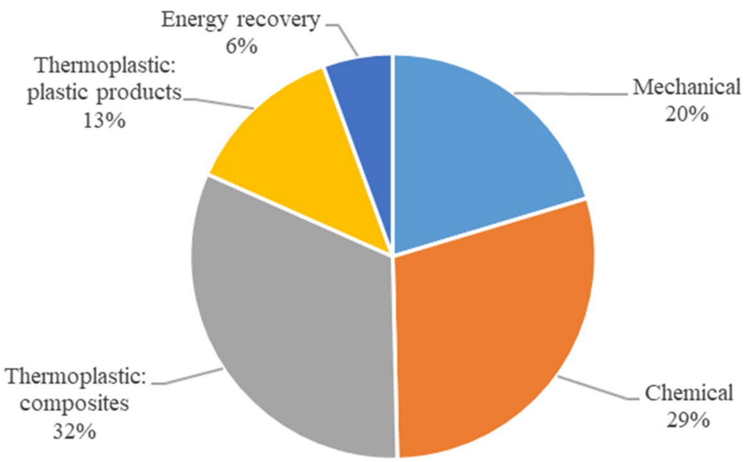

Figure 39 Share of costs between recycling processes and energy recovery

Figure 40 illustrates the distribution of the costs per ton and the staples illustrate the four different sorting alternatives and combinations. The overall processing costs, including pre-processing, recycling processes and energy recovery, form the largest share of the total costs. That is approximately 60 %, depending on the chosen sorting alternative. If manual sorting would be the first alternative until sorting technology is developed enough, it would seem as if the last alternative would be the less costly option in comparison with the first alternative, but as sorting technology develops, the centralized alternative allows efficient investment in sorting technology.

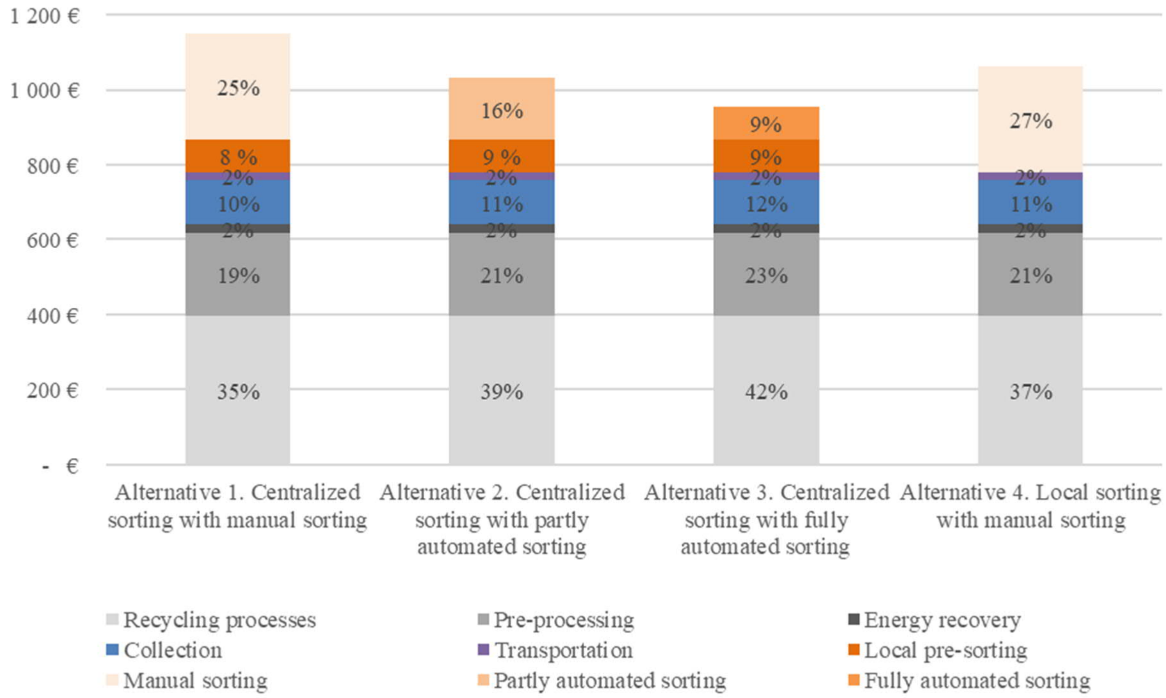

Figure 40 Costs (€/ton) of sorting alternatives in the model

The first cost model of the textile recycling process was developed during the previous Telaketju Tekes -project, including the different phases of the textile recycling system such as the collection, sorting and mechanical and chemical recycling of the material, as well as transports. The sorting part of the first developed model includes alternatives for both local and centralized sorting. The model also includes the options manual, partly automated and fully automated sorting for centralized sorting, whereas local sorting only includes the manual option. The centralized sorting in the model includes a local pre-sorting phase, to remove contaminating materials. The full report by Hinkka *et al.* (2019) of the first version of the model provides a more detailed description of the first phases of the model.

The model was updated in the current project. Model updates included e.g. that mechanical pre-processing was added for all recycling processes and thermoplastic recycling was added as an update to the previous model as well as energy recovery for rejects that cannot be recycled. - The costs for the mechanical recycling and chemical recycling processes were, however, taken from the first version of the model.

The material fractions that the textiles would be sorted into the material sorting phase were first identified in interviews, which resulted in 14 specific fractions. Furthermore, the most suitable recycling processes for each fraction were identified, resulting in four different recycling processes and energy recovery: mechanical recycling, chemical recycling, thermoplastic recycling to composites or plastic products and incineration for energy recovery for those that cannot be recycled with current technology. The recycling processes to be used in the model were identified based on what was planned to be available in Finland, and, therefore, for example, chemical recycling for synthetic materials was excluded as a recycling process.

The implemented material fraction shares in the model were identified by first conducting a literature search on available data about material fractions in textiles, mainly from end-of-life textile sorting studies but also regarding production and consumption amounts. The search was focused on studies in other Nordic and European countries, as the textile fractions in these countries most probably would represent similar fractions as in Finland, due to a relatively similar climate and consumption habits. After finding several studies on the textile fractions, three of the studies were identified as primary sources due to applicability and reliability. The other studies were kept as secondary sources and supporting data, especially if the primary sources did not allow a specific enough estimate. The following studies were consulted for the evaluation of material fraction shares: Cura & Heikinheimo, 2016; JRC, 2014; Fibersort, 2018a; Fibersort, 2018b; Hultén *et al.*, 2016; Kamppuri *et al.*, 2019a; Laitala *et al.*, 2012; Nørup *et al.*, 2018; Textile Exchange, 2019.

Investments of e.g. machinery are only included in those recycling processes for which existing industrial scale processes in Finland do not exist, which are mechanical and chemical recycling. For thermoplastic recycling, only processing costs were estimated in the model, as there are existing processes for thermoplastic recycling in Finland. Furthermore, only processing costs for energy recovery were also included, as the incineration plants already exist.

For validation of the model, a validation workshop was first held for discussing the model, where the model was presented with a focus on the changes done in updating the model in the second phase. The material was then sent to those not able to attend, to get the best possible outcome of the model with a wide expertise to comment the model and how it should be improved. The validation resulted in adjustments of the model, such as in the material sorting fractions and in the thermoplastic recycling components. Adding mechanical pre-processing as a phase for all recycling processes also resulted from the validation discussions. Manuscript for scientific article including the modelling work is in preparation.

Publication https://telaketju.turkuamk.fi/webinaarit/kustannustehokas-tekstiilikierratys/

6.4 Recycling Demonstrations

Recycling demonstrations aimed to both textile-to-textile recycling (Chapter 6.4.1) and recycling of textile materials into technical products (Chapter 6.4.2). The textile fraction used in these demonstrations were collected from our partners, they contained both consumer and technical products and pre-consumer materials i.e. side-streams, and post-consumer materials.

Our main activity was a so called *Spanish demo*, which provided different materials for both textile-to-textile and technical materials demonstrations. Companies also participated for making yarn and fabrics materials (subcontracted from Col&Bri) and making products demonstrations. Materials for technical product demonstrations were also collected from our partners and networks in Finland.

6.4.1 Textile-to-Textile Recycling

Fibres

Mechanical shredding and opening trial was carried out in co-operation with a Spanish company Col&Bri (referred in following chapters as *Spanish demo*). Different textile fraction were collected by LSJH from Telaketju partners and network. Shredding was successfully carried out without any particular problems. It was observed that, the shorter the fibre in the raw material, the bigger the dust and thus the waste. In addition, the small batch size did not enable an adjustment or optimization of the shredding process, with larger batches, outcome qualities can expect to be better.

However several material fractions were obtained from fibre opening (referred in the following chapters as ESP1, ESP3, etc). Wear and tear and poor original quality of post-consumer fractions led to relatively poor quality and short fibre lengths. In general, the fibres resulting from the batches are not the best ones because of their length and the amount of contaminants in the outcome. Two examples of opened fibres batches from materials delivered by Telaketju partner companies:

Mirka delivered technical warp knit, 100 % polyamide (PA) to opening trials. Fibres were relatively long, 70–100 mm, however, a lot of unopened pieces of fabric are included, see https://telaketju.turkuamk.fi/uploads/2021/04/57db9400-mirka-oy-en.pdf and Figure 41a). These pieces of fabric were an obstacle to the use of the fibre in spinning or in Mirka's own production process, but the material was suitable for pelletizing and injection moulding as such - see *Composites* in Chapter 6.4.2.

Touchpoint delivered woven work wear composing of PES 65%/CO 35% mixture, see https://telaketju.turkuamk.fi/uploads/2021/04/88dbff05-touchpoint-oy-rester-oy-en.pdf and Figure 41b. Material was expected to be suitable for making yarn, nonwovens and composite.

Figure 41 Opened fibres from a) technical PA warp knit from Mirka and b) woven PES/CO work-wear from Touchpoint

LSJH gathered post-consumer textiles to opening and other project partners industrial waste, reclamations and cutting residues. Ten batches, over 10 000 kg, were sorted to different fractions. Sorted materials were CO, PES, CO-PES and PA. Industrial waste did not need separate sorting, because the material base was known. All textiles were sent to LSJH, where hard parts were removed with the help of Turku AMK students. The removed hard parts included buttons, zippers, large prints, rubber bands, rib knit and tags.

Altogether 10 batches, listed below, were sent to Spain by LSJH:

- post-consumer CO, hand sorted from LSJH (ESP1)
- post-consumer CO, NIR sorted/100%, pale colours, from LSJH (ESP3)
- post-consumer CO, NIR sorted/100% from LSJH (ESP4)
- post-consumption work wear mix from Image wear and Topper (ESP8)
- post-consumer knitted mix from: LSJH (EPS10)
- pre-consumer (cutting waste) PA from Mirka (ESP12)
- post-consumption 100 % CO hand towels from Lindström (ESP13)
- pre-consumer (customer reclamation products) knitted CO elastane blends from Nosh (ESP14)
- pre-consumer (customer reclamation products) polycotton (CO-PES) from Pure Waste Textiles (ESP15)
- post-consumption polycotton workwear from Touchpoint (ESP16)

Col&Bri has Margasa fibre opening machines, open-end spinning machines, Picagno weaving machines, and Dornier weaving machines.

Samples of opened fibres were sent to Finland. The materials were used material, processing and products demonstrations, most of which are presented in the following chapters. These included:

- VTT carried out ring-spinning and composite trials - see *Yarns* below and *Composites* in Chapter 6.4.2
- Companies had a possibility to order yarns and fabrics from their batches from Col&Bri in order to produce product demonstrations - see *Fabrics* and *Products* below, and also Bachelor's thesis work by Enni Arvez/LAB studied properties of fabrics http://urn.fi/URN:NBN:fi:amk-202104296286

Earlier publication about *Spanish demo* https://telaketju.turkuamk.fi/blogi/virtuaalimatka-demojen-ihmeelliseen-maailmaan/

Yarns

A ring spinning demonstration was carried out by VTT. It showed that the mechanically opened fibres from post-consumer textiles can be produced to yarns with ring spinning method, Figure 42. However, mechanical opening decreased the fibre length so that the addition of longer fibres was needed to enable the processing. The opening quality, the share between opened fibres and unopened fragments, and the remaining fibre lengths after the mechanical opening influenced the yarn spinning process. In the ring spinning process, unopened fragments had a pronounced effect on the processing, i.e. unopened fragments caused yarn breakages.

Figure 42 Ring spun yarns from mechanically opened fibres from post-consumer textiles. Mechanically opened fibres were blended with virgin viscose fibres (length 40 mm) in ratios of 1:3 and 1:2.

The ring spinning demo was carried out by VTT in co-operation with Tampere University. Mechanically opened fibres were from the *Spanish demo*. Mechanically opened fibres were mixed with virgin viscose fibres and carded. The carded webs were drafted twice to form slivers, and the slivers were combined to form a roving, which was spun into yarn with a ring spinning machine (Ring Lab 3108A, Mesdan, Italy). For earlier publication about results see https://telaketju.turkuamk.fi/en/presentations-en/finnish-swedish-textile-circularity-day-14-1-2021-2/

Fabrics

Seven fibre fractions were spun in yarns via open-end spinning and woven into fabrics at Col&Bri (subcontracting by companies). Warp yarns in all samples consisted of recycled 50% PES and 50% CO (provided by Col&Bri). The weft of the fabrics was a blend of 30% recycled PES (provided by Col&Bri) and 70% recycled materials from Telaketju partners. See examples of yarns and fabrics in Figure 43.

Figure 43 Appearance of yarns and fabrics made from mechanically recycled materials (EPS1,3 and 8)

Six of these fabrics, composed of polyester and cotton blends with a different fibre composition (see Table 12), were included into a study of a wide range of mechanical and other textile properties in order to evaluate how well they would suit for different types of apparel. An evaluation was carried out by comparing the results to Euratex Technical Clothing Group’s Recommendations to gain a reference for textile properties (Euratex, 2006). The appearance of the fabrics were mostly grey with some colour variation, see the fabrics in Figure 44.

Table 12 Weft origin of recycled fabrics

Material fraction used as weft	Weave structure	Material batch code
Manually sorted cotton	twill	ESP 1
NIR identified CO + 3% unknown	plain weave	ESP 3
65% PES 35% CO, recycled work wear	twill	ESP 8
Mixed knitwear	twill	ESP 10
Recycled cotton + 3-5% elastane	twill	ESP 14
40% PES 60% CO	twill	ESP 15

Figure 44 Fabric samples made out of mechanically recycled textiles and test ©Taru Marttila

Colour fastness in washing and in general was very good, as expected since the coloured yarns in the fabrics were made of used post-consumer textiles. However, their dimensional change was found to be high in the direction of warp (5 % - 8 %) while much better otherwise (1.5 % - 3 %), see Figure 45. The Euratex recommendations suggest a dimensional change of 2% or less for all clothing textiles.

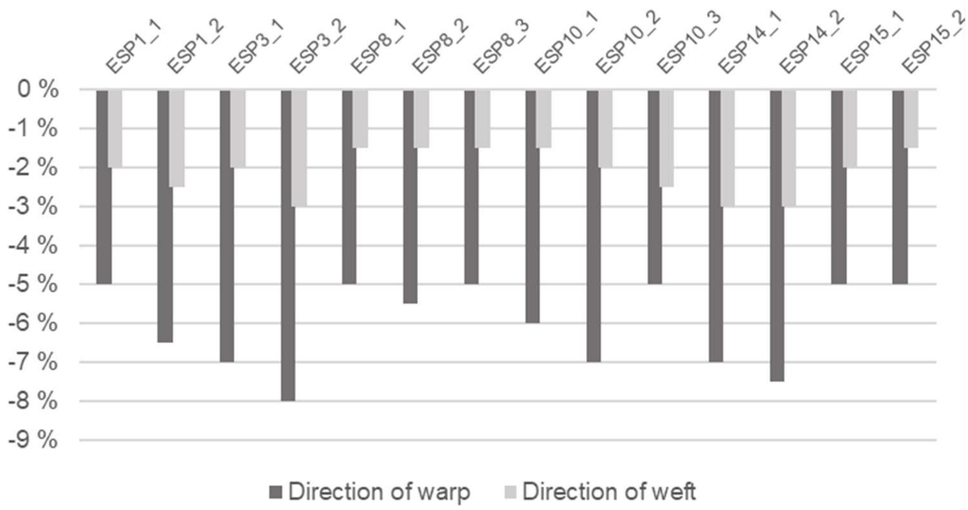

Figure 45 Dimensional change of textiles (Arvez, 2021)

A high variation in abrasion resistance was observed with some concurrent samples of some textiles, but four samples reached the proposals' suggested 16 000 revolutions for clothing textiles. One sample broke at 10 000 (with concurrent samples at 14 000, 25 000 and >30 000 revolutions) and another sample at 8 000. In all cases, high pilling was observed. Within a separate pilling test, two samples reached the recommended limit for all clothing textile categories of Euratex recommendations, while the rest were clearly much more affected.

The tear and breaking strengths of some of the studied samples were clearly higher than the suggested Euratex recommendation of 1.2 daN, and even the weakest sample fitted the criteria for clothing textiles. Even though these fabrics felt generally soft and relatively loose, the results indicated that they were strong and quite resistant to tearing.

Figure 46 Test pieces being prepared for tensile tests, and test in process ©Taru Marttila

As a conclusion these fabrics would not perform well as clothing materials, mostly because of the high pilling and dimensional changes in washing. The highest dimensional change is in the warp yarn, which is the same with every fabric sample. Aside from pilling, general abrasion resistance was poor with the plain weave sample (ESP3). The suggested abrasion resistance for most clothing materials is above 16 000 revolutions, which two fabric samples could not reach.

A summary of the specific failures of the samples tested against Euratex recommendations is presented in Table 13. It can be observed that each sample lacks a dimensional stability in washing to fill the use, but if this, and pilling properties, are overlooked, ESPs 8-15 could be used for most clothing textile applications.

Table 13 A summary of the failures of the samples tested against Euratex recommendations

Application	ESP 1	ESP 3	ESP 8	ESP 10	ESP 14	ESP 15	Warp
Coat	▲●	▲●	■●	■●	■●	■●	●
Jacket	▲●	▲●	■●	■●	■●	■●	●
Knitwear	X	X	X	X	X	X	X
Anorak, sportswear	▲●	▲●	■●	■●	■●	■●	●
Pyjamas, nightwear	●	▲●	■●	■●	■●	■●	●
Shirts, dresses, blouses	●	▲●	■●	■●	■●	■●	●
Lingerie	●	▲●	■●	■●	■●	■●	●
Lining	●	▲●	■●	■●	■●	■●	●

● = Dimensional change ■ = Pilling ▲ = Abrasion resistance

These tests were performed as a part of Bachelor's thesis work by Enni Arvez/LAB (Arvez, 2021). The tests performed were based on standardized laboratory methods: Abrasion resistance (ISO 12947-2), Pilling (ISO 12945-2), Tensile properties (ISO 13934-1), Tear properties (ISO 13937-3), Colour fastness (ISO 105 and according to ISO 6330), Dimensional stability in washing (ISO 5077).
Thesis (Arvez, 2021) available on-line http://urn.fi/URN:NBN:fi:amk-202104296286

Products

Several product demonstrations based on materials processed at Col&Bri were made by companies.

LSJH collected different fractions, cotton as well as mixed knitted materials, of post-consumer textiles for opening and processing. In the mechanical opening of the textiles, the fibres were shortened, thus requiring blending with a recycled polyester. Some of them were spun into yarns and test fabrics were made from the yarn (ESP 1, 3 & 8). Product demonstrator was produced in co-operation with Eetta Saarimäki (see Figure 47a and https://telaketju.turkuamk.fi/uploads/2021/04/70a56291-lounais-suomen-jatehuolto-oy-en.pdf).

Pure Waste collected their own used textiles i.e. those were originally made of recycled fibres. The fibre composition was 60 % mechanically recycled cotton and 40 % r-PET. Woven fabric with basis weight of 200 g/m^2 was made and used in aprons made for Touchpoint (see Figure 47b and c, and https://telaketju.turkuamk.fi/uploads/2021/04/938dd640-pure-waste-textiles-oy-en.pdf).

Image Wear Work wear, mostly woven and mostly PES/CO, 100% PES, 100% CO. Twill fabric and yarn, composition: recycled CO 70%, PES 30%. The material has been tested as an apron (see Figure 64c and https://telaketju.turkuamk.fi/uploads/2021/04/537cc6bb-image-wear-oy-en.pdf) and other products are coming.

Nosh collected knitted underwear material. Opened fibres were used to produce yarns and CAIROL Twill fabric with an areal density of approximately 230 g/m^2. The product demonstrator is a Zero waste bag, which was dimensioned so that no waste occurs (see Figure 47d and https://telaketju.turkuamk.fi/uploads/2021/04/42ea373b-nosh-company-oy-en.pdf).

Figure 47 Appearance of company demonstrations: a) oven mitten and pot holder, b), Pure Waste yarn and fabric, c) Apron made from Pure Waste fabric by Touchpoint[17], and d) TAHTO zero waste bag by Nosh Company

[17] https://www.touchpoint.fi/ajankohtaista/vastuullisten-essujen-uusi-tulokas-vellamo

6.4.2 Technical materials

Composites

The purpose of the composite demonstrations was to figure out, what kind of materials can be recycled to new composite materials, what are the limitation and what aspects has to be taken into account.

In the first study, thirteen polyester pillow fillings were analysed with DSC by VTT. This test showed the complexity of recycling of post-consumer textile products. Even though all the fillings were polyester nonwoven fibres, the melt temperature of polyester samples varied by almost 15°C (from 236°C to 249°C). It has been noticed in earlier tests, that it is favourable to compact the material at as low a temperature as possible in order to avoid degradation of polymer chains during the process. Low compacting temperature with a varying melt temperature, however led to the result, where some or the material turned into fluid, whereas others remained partly in fibre form (Figure 48).

Figure 48 Compacted polyester pillow fillings

Within a second study, compounding trials were carried out with the cylindrical extruder Modix, developed by VTT. The benefit of Modix is a large diameter of screw and feed opening in short machine, compared to the traditional plastic processing methods. This method enables the feeding of light and fluffy materials to the process without pre-processing stages of the textiles.

Tested materials were post-consumer opened fibres (CO and polycotton) together with melting component (PP), industrial waste (including PA, PES, PUR and mixture materials) and whole textile products (mops) together with PP (see examples in Figure 49). Additionally, base paper and film waste from fabric cutting was processed to composite material. Materials were first compacted with Modix and then grinded to a form that can be processed with traditional plastic processing methods (see samples in Figure 50).

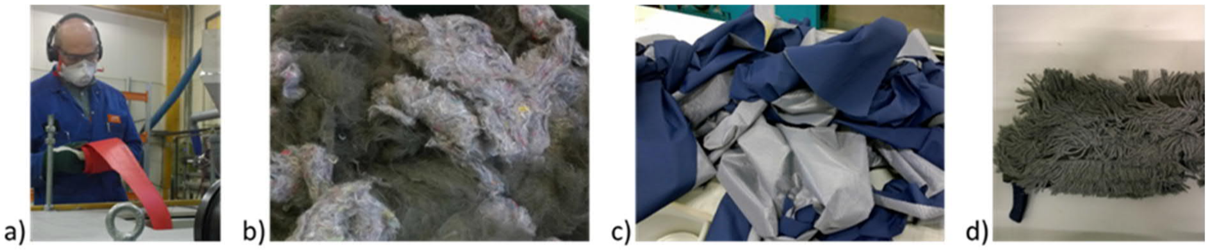

Figure 49 Examples of different forms of materials fed to the Modix extruder a) fabric stripe, b) fluffy CO/PP mixture, c) fabric pieces tied together and d) whole mop with PP addition

Figure 50 Examples of compacted (left) and grinded (right) materials

Fourteen selected compounds were injection moulded to tensile bars. Formulas of each composite/ material is presented in Table 14 and examples of tensile bars are shown in Figure 51. When necessary, additional components were included into the mixture. These other component included other type of recycled textiles, new commercial PP granulates (BH 374 MO from Borealis), and compatibilizer (Lotader). Prior to the injection moulding, materials were thoroughly dried according to guidance of the general processing procedure of each material.

Table 14 Compacted formulas of the textile recyclates (including code used in following figures)

Main component	Other components	Code
40 % Hand towels 100 % CO	60 % new PP	KP01
50 % Polycotton workwear (Touchpoint)	48 % new PP, 2 % compatibilizer	KP02
40 % 100% CO (NIR) (LSJH)	60 % pre-consumer PP waste, black opened fibres (Freudenberg)	KP04
40 % Work wear mix (Image Wear & Topper)	60 % pre-consumer PP (same as above)	KP07
100 % 3*PA (thick felt) (Valmet)		KP10
100 % 3*PA + PUR (thick felt) (Valmet)		KP11
100 % PA/PES (light blue) (Valmet)		KP12
100 % PES lot of stabiliser (red) (Valmet)		KP13
100 % PES little stabiliser (red) (Valmet)		KP14
50 % PA cutting waste (Mirka)	48 % new PP, 2 % compatibilizer	KP03
100 % PA cutting waste (Mirka)		KP06
60 % film + base paper	40 % new PP	KP08
67 % Mops (Freudenberg)	33 % pre-consumer PP (same as above)	KP17
100 % PES (2*PES +TPE) (Reima)		KP19

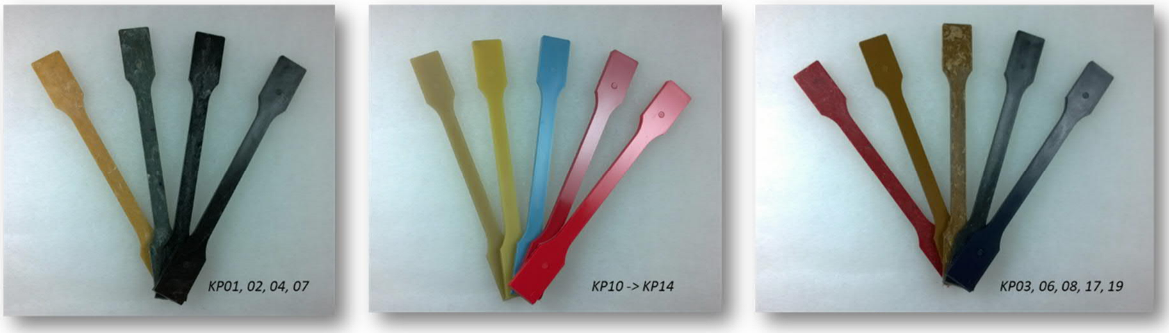

Figure 51 Injection moulded composite material samples from textile recyclates (see contents from Table 14)

Injection moulded samples were further tested with Instron to evaluate the tensile strength (Figure 52) and stiffness (Figure 53) of the materials. The best mechanical results were achieved with such as compacted materials (PET, PA) and CO/PP-composites from opened fibres. Results are comparable to general values for corresponding materials reference materials, in this case PP (BH 374 MO, Borealis), PET and PA6. CO-fibres reinforced the composite in final product and the tensile strength increased compared to the original PP (used as melting component in composite). Compacting the polycotton with PP increased the stiffness, but the tensile strength remained at the sample level compared to PP alone. Some samples were visually dry after compacting (especially base paper with film from cutting room and mops), which can also be seen as lower mechanical results.

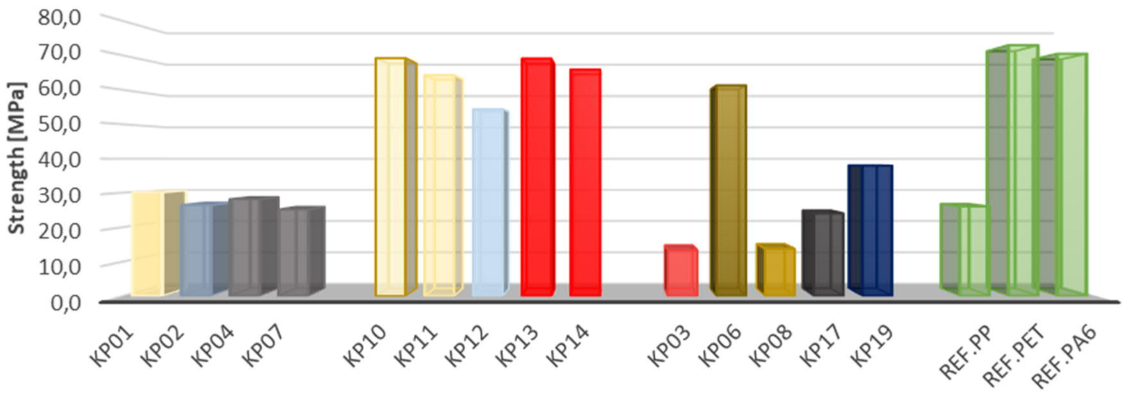

Figure 52 Tensile strength of the injection moulded textile recyclates (general reference values on the right)

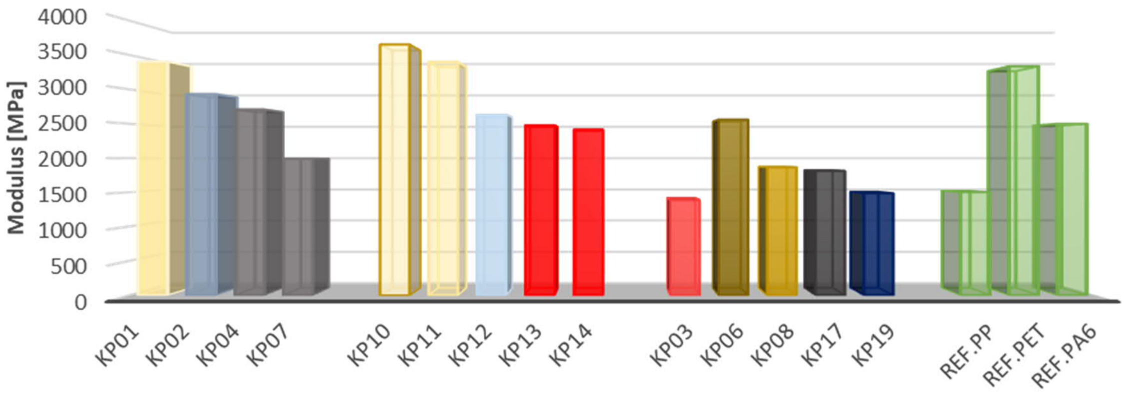

Figure 53 Stiffness of the injection moulded textile recyclates (general reference values on the right)

Melt processing with a modular mixer showed the potential of recycling fabrics to composites. Different types of textile fractions, difficult for mechanical recycling, can get a new life as a new product through melting process. Increasing the ratio of melting component, would have improved the visual quality of the dry compounds and, most probably, increased the mechanical properties.

Materials in the composite demo were first compacted with cylindrical extruder (Modix), developed by VTT. See more information e.g. via https://www.vttresearch.com/en/news-and-ideas/vtt-develops-novel-device-processing-problematic-waste , https://www.youtube.com/watch?v=-A8AEwz8JEQ

Several project partners sent different types of material fractions (difficult to mechanically recycle) to composite demo. Companies involved to this demo were: LSJH, Touchpoint, ImageWear & Topper, Mirka, Reima, Valmet and Freudenberg, Suitability of recycling of these materials to composites with the modular mixer (Modix) was evaluated. Results have been published earlier: https://www.youtube.com/watch?v=q-vjGzbXfxI&list=PLH6Y5d-7NfA_d9aSMqApkvC175nLy6qKS&index=2

Paper-like products

Currently, textiles made of mixed fibres are difficult to recycle. Yet, a majority of clothing textiles are made of mixed fibres for several reasons. New recycling methods and monomaterial clothing are under development, but there exists a process where almost any kind of textile can be used and recycled: paper making using rags (discarded clothes). Using rags to make paper for apparel purposes is somewhat questionable due to its poor durability properties. Using wax coating abrasion, moisture and tearing resistance can be improved. However, the touch and fluidity still remain paper-like. The rags paper containing only 65% PES and 35% CO and coated with bee wax showed promising results if compared to the same paper without the wax coating. During a Martindale abrasion test the material started to change its appearance to leather-like after 10,000 rounds. After 30,000 rounds the material's appearance still remained unchanged, Figure 54. The moisture resistance improved significantly. Wax coating prevents the material to getting wet thoroughly meaning that it would protect the objects inside if used as a surface material in a bag. The tearing resistance improved satisfactory, but requires further development and limited usage in products or parts where flexibility is not required. This will provide new possibilities for sustainable product design using paper making process for manufacturing small quantities of recycled material utilizing mixed fibre textiles as raw material.

Figure 54 Bee wax coating on rags paper (discarded clothes) made merely of 65% PES, 35% CO after 30,000 rounds in Martindale test shows no wear and tear. Different colour fibres originate from discarded mixed fibre clothes. The texture of the paper is smooth and leather-like. Photo: Minna Cheung

Handmade discarded textile paper was made in the Painovoima workshop. The coating trials and tests were run in the LAB materials testing lab. The aim was to find maximum content of mixed fibres in textile paper in order to reduce the amount of 100% CO and to add durability by using different coatings. Four different pulp versions were made for testing: **1.** 100% of 65% PES, 35% CO, **2.** 90% of 65% PES, 35% CO and 10% of 100% CO, **3**. 70% of 65% PES, 35% CO and 30% of 100% CO **4.** 50% of 65% PES, 35% CO and 50% of 100% CO. Versions 1 and 3 were tested for abrasion resistance using Martindale with 9 kPa pressure. Moisture resistance was tested by using 2 min. water sprinkler and surveying the back side of the material. Tear resistance was tested by using WEAP Elmendorf.

Felts

Wool fibres, from the side flow of a wool carding process, were well suited for needle-punching process. The felts were even and processing easy, Figure 55. Additionally, mechanically opened polyamide fibres, whose opening was difficult and large fragments were left in the sample, were possible to card and needle-punch when mixed with woollen side stream fibres. The unopened fragments caused dots to appear on the felt, but they did not have an effect on the processing (carding and needling).

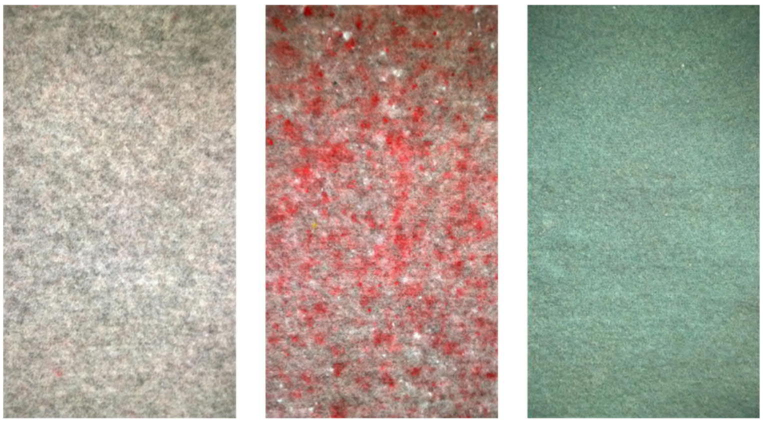

Figure 55 Needle punched felts from left to right: first made from side flow wool fibres; second made of side flow wool fibres mixed with mechanically opened polyamide fibres; and third made of lightly washed and dyed green wool fibres.

The needle-punching demo was carried out by VTT together with Tampere University. Wool fibres were side stream from the wool carding process (short, brown fibres) and washed, dyed and carded (green fibres). Additionally, mechanically opened fibres (white and red polyamide fibres) were from the *Spanish demo*. The side stream wool and polyamide fibres were carded and folded for the needling. The needle-punching was carried out with nonwovens production line (Automatex, Italy) and needling frequency was 300 strokes/min.

7 Product Information in Circular Economy

Product information in linear economy has been mainly focusing on how products are made including, for example, material and structural information as well as information about actors in value chain. Need of this type of information exists also in circular economy. Its importance has also been increased when the sustainability and responsibility of textile production has raised into general awareness. However, since both products and materials will cycle in circular economy, this introduces new needs for gathering and using data and adding value from data for different actors in value network.

There are lots of information regarding textile products starting from fibres and yarns to fabric type and garment properties. Many of these are not needed in linear economy once a product is made, but in circular economy, these are affecting the possibilities of product and material cycles (Heikkilä *et al.*, 2019). Some examples of such data is illustrated in Figure 56. Some of these can be partly observed visually (knitted and woven fabric structure) or determined by educated guess (dye chemistry based on fibre information), or studied in lab (e.g. yarn strength). However, most of these are too difficult or even impossible to determine later-on, especially when limited to non-destructive methods.

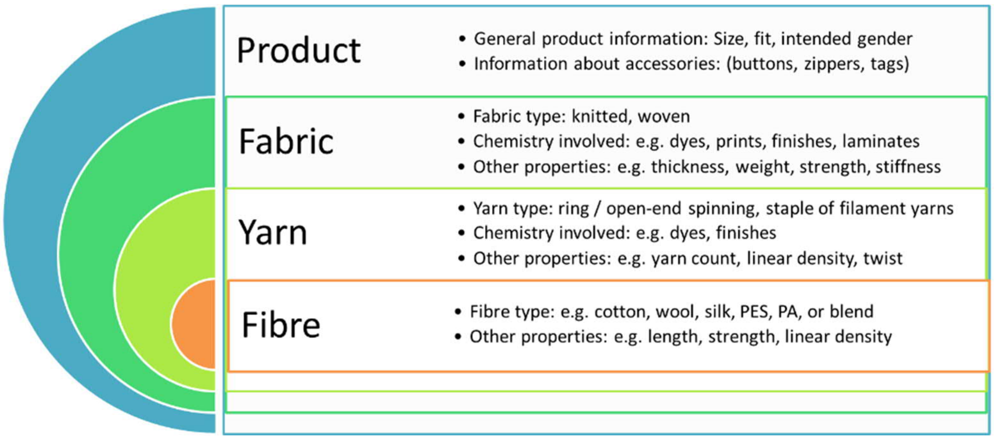

Figure 56 Some examples of product information

In addition to these textile products have haptic properties that cannot easily be determined nor communicated. These include feel, wear comfort, propensity to static build-up, or drapability, which are kind of summary outcome of several material and product properties from fibre selection through yarns and fabric properties to product construction.

New textile products are attached with certain information some of which are required by regulation in EU and many other countries. The required information include, for example, the manufacturer or distributor name, material contents and care instructions. Additional information may be asked from manufacturer or distributor.

Traceability and transparency and is an important part of a socially and environmentally responsible textile value chains, thus, an important part of due diligence work (OECD, 2017; Richero & Ferrigno, 2016; UCENE, 2017). Textile companies (producers and retailers) should be able to explain how it identifies and addresses actual and potential risks in its own operation and with the supply chain including subcontracting. Such risks regarding human rights and animal welfare, as well as labour, environmental and integrity risks. Textile companies are thus expected to '*develop information management systems that are accurate and current and are capable of storing the full extent of information necessary to conduct due diligence*'. UCENEs report (UCENE, 2017) state that '*improving traceability has, therefore, become a priority for the industry, in order to increase its ability to manage its supply chains both more efficiently and sustainably*'. Within OECD guidelines for footwear and textile sectors actors are encouraged to work towards sharing information and identifying supply chain (OECD, 2017). Traceability and transparency are tools to inform and engaged different stakeholders including users. The availability of value chain sustainability is a requirement for voluntary standards and certificates (see Chapter 4.3.2), and aware and ethical consumption is a raising trend (Richero & Ferrigno, 2016).

7.1 Information within Product Cycles and Materials Cycles

In circular economy, products contain recycled materials and/or they are planned to be recycled. Communications of these aspects are needed. Labelling of circular products containing recycled fibres may be challenging, and additional product information would be beneficial for communication recycled content to value chain and customers. Textile labels or markings are only allowed to use fibre names listed in standard, but does not have any terminology for addressing recycled fibres. Exact fibre composition may not be known if using mechanically recycled fibres, since sorting processes have some limitations, and if aiming for an exact composition in sorting, losses will be high. Tolerance in stating fibre composition is 5 % for carded fibres and 2 % for others (EU, 2011). While care instructions are already indicated on textile labels and marking, in circular product also End-of-Life instructions may be of interest to be included, i.e. is the product recyclable and how, and is there a possibility for the customer to return the product to the store or to the producer for recycling

In circular economy, for example, in sharing as well as in re-use models, products will move from one user to another. There may be dealers in between. In re-use cycles information about the condition of the product and its materials may be crucial. The users will get products maintained or repaired. Remanufactures get used products from users. During the lifetime of the product, there may be multiple different actors – users, dealers or handlers – who need or could benefit from product information as well as re-use history including information of modifications, repair and remaking history.

When the product circulate, the original product information tends to vanish. And if the information about the manufacturer or the product identifier have vanished, it is also very difficult to search for information. In such a case, the product itself should be examined to get information. For example, many textile fibre materials can be at least qualitatively identified with current technologies. Plenty of general information is also available if it can be matched to a specific product.

Circulation is also an opportunity to collect new product information. Information about usage and modification history, user experiences and the condition of the product may be collected and utilised during circulation. Such information is valuable for designing and manufacturing new products as well. Circular economy enables the collection of much more use-based information per product than linear economy.

After use and re-use cycles, when the product is no longer usable, the product will be dispatched to recycling. For the recycling of materials, the first step is collecting and sorting of discarded textiles. Fibre composition and chemical content is crucial for most recycling methods (Heikkilä *et al.*, 2019). Sorting can be done either manually, by assisted or automatized sorting system. Hand sorting is based on the operators' hand-feel and knowhow, or reading labels. Neither of these systems are accurate. Current recognition systems for textile sorting are mainly based on NIR identification of the textile fibres in textile products, but there are limitations to these methods (e.g. Kamppuri *et al.*, 2019b). Textile sorting may benefit from tags or other identifier systems containing fibre composition as well as information of any structural component or chemical content which may limit its suitability to recycling processes or possible end uses. The chemical load of recycled textile may include, for example, persistent functional chemicals from textile finishing treatments such as flame retardants, soil or water repellence finishes. The presence of certain chemicals may be considered to be contaminants that are restricted in textile products aimed for skin contact or to be used by children, and therefore limit possible uses of secondary/recycled fibres (Kamppuri *et al.*, 2019a; Dahlbo *et al.*, 2015).

The marking of new materials and products made of secondary raw materials is challenging, especially if recycled materials are from post-consumer origin and collected from consumers. Its cycling history would be interesting, but marking materials in a way that it can be still recognized after, for example, chemical of thermoplastic recycling process is challenging. Most of the recycling methods (e.g. chemical recycling) require large volumes of materials and it is not possible to keep small known batches separate. In addition, there are currently no quality standards for recyclates.

7.2 Value of Information in Circular Economy

The scope of the value examination in this chapter is especially the value for supporting textile circular economy. In practice, this means that the data will support some of the circular activities mentioned above. Plenty of information is valuable, both for new products as well as circulation. In such cases, the viewpoint of circularity is especially discussed.

The value of product information for a person or organisation is based on the need for information. Needs may be various, but, basically, there are two kinds of needs for product information: 1) information to support an acquisition decision, and 2) information to support use of the product. Information to support circulation and discarding decisions and actions may be classified as a third category or as a part of the information to support the use of the product.

The lack of information may prevent an acquisition, cause damage to the product during use, or cause some harm when circulated or discarded. On the other hand, certain information may be conclusive to an acquisition, long life of the product, good user experience, fluent circulation and sustainable discard.

There are different levels of needs. Concerning personal needs, Maslow's hierarchy may be referred to. It consists of three categories (and five levels): basic needs (physiology and safety), psychological needs (belonging and esteem), and self-fulfilment needs (self-actualization). They may also be divided into deficiency needs and growth needs. The former means that you feel that something is lacking and the need will weaken more, the better it will be satisfied. The latter means that you desire something (rather that lack). Simplifying, it may be said that we have *essential*, *beneficiality* and *flourishing* needs – that is, for example, the information may be essential, useful (but not critical), and a key for success.

It may be expected that the (exchange) value, in general, follows the same hierarchy. For example, the essential information is mostly expected and regulated to be included free, even though (or because of) it is most badly needed. Concerning textile products, these include instructions for use and care, material content, and the country of manufacture, which were assessed as the three most important information categories in the consumer survey (see Figure 12 and Figure 15 in Chapter 3). On the other end of the hierarchy, the information that will make you or your business flourish will be valued highly.

The aim of circular economy is that products will have a long life. It means that there are several opportunities to utilise product information about each product. This increases the utility value of product information and makes it more worth collecting, storing and managing information about a circulating product compared to the products having a shorter life. The information of the new product, for example material information and care instructions, is needed also in sharing, maintaining, reuse and refurbishing. And the collected use-based information is also beneficial for designing and marketing long-lasting new products.

The product information that is especially valuable in textile circular economy includes:

- evidence on sustainability and responsibility
- evidence on quality and durability
- evidence on safety (clean, free of harmful chemicals)
- fitting and comfortability
- condition (of product and material)
- use, care and recycling instructions

- exact material content
- user experiences and product history (may include many kind of information)
- availability (used products and recycled materials).

The information that is especially valuable to support circularity includes evidence about positive impacts on *sustainability*, and evidence about the *quality and safety* of circulated products and material. The former is important, because it is a strength of circular economy compared to linear economy. This notion is supported by the results of a consumer survey as shown in Figure 57 and Figure 58 (see Chapter 3 for details of the survey). The survey also showed that those who were interested in using circulated products assessed the importance of circularity and environmental impact related information much higher that those who were not interested in using circulated products.

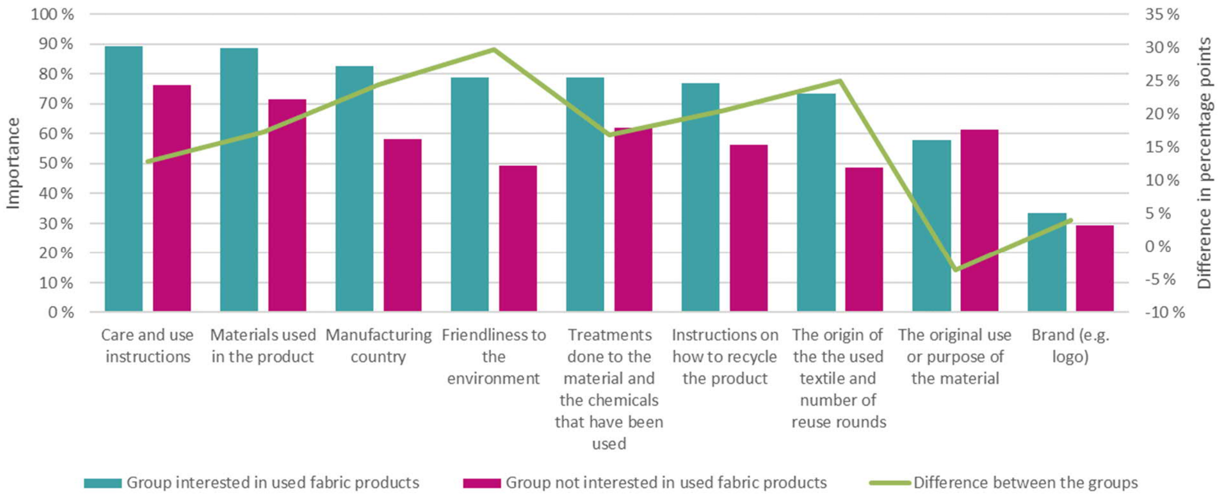

Figure 57 Importance of different product information of products made of used textiles. Comparison between two groups: those who are interested in such products and those who are not interested

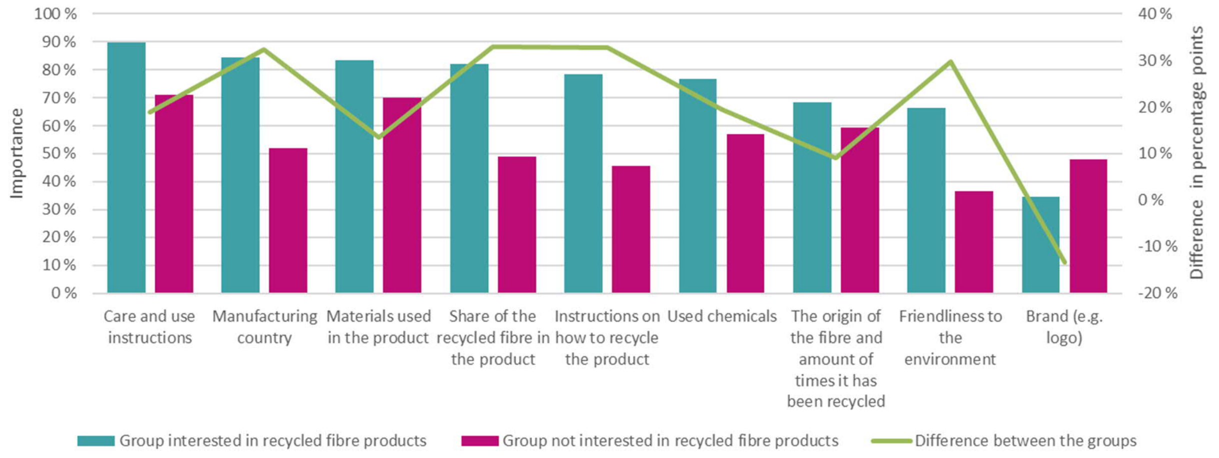

Figure 58 Importance of different product information of products made of recycled fibre. Comparison between two groups: those who are interested in such products and those who are not interested

Quality and safety information is important, because the safety and quality of circulated products and materials are often questioned. Within our consumer survey (see Figure 13, Figure 16 and Figure 19 in Chapter 3), such a worry made a big difference between those were interested in circularity compared to those who were not. Quality and durability were also found to be the most important purchasing decision criteria. It was interesting to notice that the brand of the product was the least important purchasing criteria for circulated products (Note: the survey did not include second-hand trade).

Providing plausible quality information is not a simple topic. Quality and durability are connected with the brand of the product, but building a brand is slow. The low importance of the brand noted above, may be resulted from the lack of brands, which would be strong in circulation. Manufacturers may give their propositions, examples and references on the quality. However, relying on manufacture as an information source requires that the consumer trusts it. Other users may share their experience about the product. However, in the survey, the recommendation was one of the least important criteria in all cases (see Figure 13, Figure 16, and Figure 19).

Comfortability of the product is one of the three most important decision criteria (Figure 13, Figure 16). This information is very difficult to convert to objective data. A customer typically bases this on a trial and possibly on earlier own experiences on the brand, and recommendations by other users. The situation is the same for new and circulated products, but in the case of reused products, there are possibly more *user experiences* available. The consumer survey revealed some significant differences in the importance ratings between different age groups. These are presented in Table 15 and Table 16 below.

Table 15 Importance assessments of different product information. Significant differences between different age groups (compared to the other age groups)

Age group	More important information	Less important information
Youngest 20–29 years	Brand information when recycled (still low)	Country of manufacturing when recycled (still quite high)
Middle 30–44 years		Environment friendliness when recycled
Oldest 45–65 years	Recycling instructions Treatments and chemicals	

Table 16 Importance assessments of different decision criteria. Significant differences between different age groups (compared to the other age groups)

Age group	More important criterion	Less important criterion
Youngest 20–29 years		Lack of environmental impact information
Middle		
Oldest 45–65 years	Recyclability Nearby production Lack of environmental impact information Lack of responsibility	

7.3 Product Information Management in Circular Economy

In circular economy, a product circulates. Even the production and delivery of a new product involve and extensive number of parties. New products are mostly produced in developing countries by multiple producers in a network. This makes it challenging to collect information, for instance, for sustainability assessment. The textile industry does not widely use information technology because of a lack of skills and facilities in developing countries but also because of the conservative nature of the industry even in western countries. Circulation still increase the number of stakeholders substantially.

Circular economy sets new requirements and give new opportunities for product information management. In linear economy, the product information is mostly created, collected and applied during the design, production and retail of a product, whereas in circular economy, the need and collecting of product information extend much longer and wider. Furthermore, each party of production and retail sequence manage, by themselves, the specific information they need, and some quite limited information is given to first-hand customers. In circular economy, on the other hand, there are several different reproduction and reuse phases of the same product, in which the original product information would be needed. Circular economy also enables a much more extensive collection of user experiences than linear economy. Different solutions to meet the new challenges and opportunities related to product information management have been developed, but much is still possible and needs to be done.

Circular economy pushes towards more open sharing of product information. It would be more beneficial in circular economy than in linear economy. Currently, most of the product related information is under the control of the brand owner or spread out in the complicated production and distribution network. The owner of the information will not necessarily share it, even though it would exist. The reasons for not sharing can be various: fear of disclosing valuable information to competitors is one of the most common ones. However, often it is simply because information owners do not see what benefits they can achieve when sharing data. Different systems have been developed to improve collecting, storing and sharing product information. Some commercially available systems for textile product information management are presented in Figure 59 according to their focus on different phases of circulation.

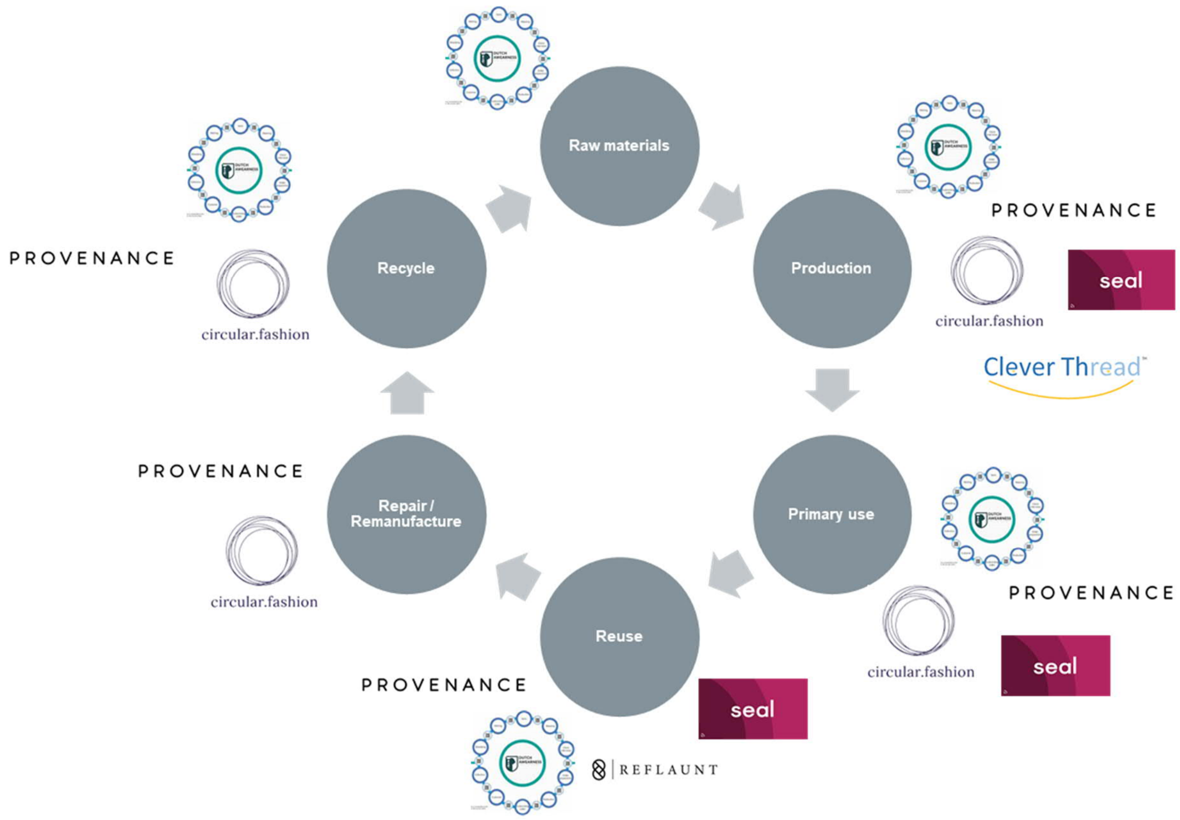

Figure 59 Textile product information systems and their focus on different phases of circulation

A system for product information management may be technically implemented in various ways, but in general, it consists of four main elements: 1) information itself, 2) user interface, 3) product identifier, and, 4) system management (see Figure 60).

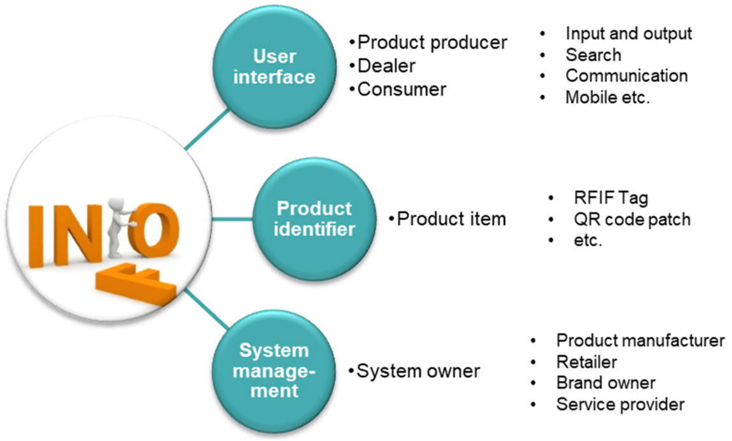

Figure 60 Elements of product information system

7.3.1 Tagging, Tracking and Tracing

Product identifier is a key information element. It makes it possible to link information to a certain product. New retailed products typically have a product code as an identifier. Such code typically identifies the brand and model of products, but not the specific product item. Textile product items very rarely have a specific code. Concerning the information related to a new product this level of identification is sufficient as well as for many different activities of circular economy. However, in some circularity activities the information about a specific item would be beneficial. For example, usage history - glorious or shameful - would be of interest in a reuse case. If the product information management system aims to share such information, a unique identifier is required for each product item. Identification is required for tracking a product throughout its production phase, as well as during the use and circulation. Identification is a key to collecting and sharing information concerning the product - except, if all needed information will be embedded to the product itself. Several technologies are available for attaching identification information to a textile product, and several services, which manage the unique coding of product items. Further, some systems also authenticate the product.

Since the life of the product is aimed to be long in circularity, the identifier should be attached reliably and durably. Users tend to remove labels from textiles - especially from clothing. Printed information also tends to wear away in use and washing, which makes such a form of information unavailable in later circulation of the product.

Technologies for marking textile products include traditional labels, printing, embroidering and RFID tags. Bar codes or QR codes may be used on traditional labels and they may also be printed or embroidered on textile. RFID tags, including an electronic identifier, may be attached to textiles and clothes.

RFID tag is a fairly new technology which stores information in an electronic format. RFID tag is a chip, which can be either sewed inside the product or attached as a label or a button. It is read by radio waves, and, thus, the information is available even though the tag is not visible, while reading other marking requires a visual contact. Reading bar codes, QR codes and RFID tags requires a proper equipment, which slightly limit their use especially in consumer solutions. However, the visual codes as well as some RFID tags may also be read by mobile phones.

QR codes and RFID tags significantly increase the amount information that can be attached to a textile product. Standard QR Codes can hold up to 3KB of data. RFID tag typically carries up to 2KB of data, but tags with a bigger capacity are available. A bigger capacity has been demanded, for example, by the aerospace industry, which wants to store histories of parts on attached tags. The information may basically contain anything: text, pictures, etc. Typical use of a tag is a *license plate* that is a unique serial number for a product item. It has been estimated that the information capacity of QR codes and RFID tags is sufficient for giving new unique serial number for every single textile product item for a long time.

RFID tag is much more suitable for automatic reading since it does not require visual contact between the reader equipment and the tag. Textile materials typically do not significantly restrict radio waves and RFID tags can be read even at 100 meters distance - depending on the technology. RFID tags are rather durable in different conditions, if they are reliably attached to a product. A bunch of products may also be identified practically at the same time, if there is no need to separate them. This is used, for example, in laundry. RFID tags are additional hard parts, which should be removed from a product before recycling. On the other hand, RFID tags may be reused.

QR code is applicable in manual reading and also in automatic reading in cases, when it can be fairly well ensured that the code stays visible and can be found in handling (e.g. in packages). RFID tag is more practical even in these cases except if for some specific reason, a radio wave reader cannot be used. The difference in costs of using either QR code or RFID tag is insignificant in standard applications.

7.3.2 Product Information Management Approaches

Information should be stored somewhere where it is safe for the required period, access to information is granted based on the needs, and it can be managed. There are various options from cloud services to the product itself. When the tag is used for identification of the product item, the actual product information is made available in an external data base, and the tag may be used for tracking the product item. The long term challenge of the external data base is how to ensure the upkeep of the data base for the whole, hopefully long lifetime of the product.

There are different options for the management of an external product data base. Every company or non-profit organization whose business is in textiles have their own systems and data bases to manage the product information that they use. These could also be extended to manage the whole lifetime information of their products. Unfortunately, companies and organizations come and go in current dynamic business environment. It may also be difficult to get all companies interested in keeping up product information years after the product have been sold. Some kind of common effort of companies and organizations (e.g. associations) could be a more sustainable arrangement for collecting and archiving product information and ensuring its availability for long enough. A public organization could be another option. If profitable business can be developed around the product information, a commercial solution could be possible, too. However, developing purely commercial solutions easily leads to competing separate systems making the use of information more complicated. If common rules for sharing information could be agreed, though, a data management system involving a multiple operator could be an option, too.

Another alternative is to attach all the information to the product itself. Then, an external data base is not needed. If the information can be attached to the product reliably, this solution clearly have advantages compared to the external data base. Even if the data would be attached to the product itself, it needs not to be totally open, if, for example, for commercial reasons certain ownership of the information needs to be preserved. A shared information management based on attaching information to the product also requires agreement and use of common data management standard. One specific question would be what should be done to the locked information if the owner of the information goes out of business (in case information locking is used)?

Some of the product information may be reproduced if it has been vanished or would not have been originally sufficient. For example, the technologies to identify the material content of textile have been developed because the material content is very essential information in textile recycling.

The user interface enables users to get information from the system or put the information in, search for information, communicate with other users, etc. There may be different types of users: parties involved in producing a product, dealers, consumers and other customers, authorities etc. The user interface may be different for different users.

7.3.3 Information for Design and Production of Sustainable Textile Products

The information collected during the circulation would be especially beneficial for the designers of products. The design and production of sustainable long-lived textile products is a corner stone of circular economy, if it is an important aspect in linear economy markets in some cases, too. This requires information about sustainability of the production chain and sharing such information together with a product.

Sustainability of a product means that it will stay in use and cycles long, and finally will be recycled. This requires the use of durable materials and fabrication methods, ensuring easiness of care and repair. Sustainable products are designed to fit their use and user in timeless fashion and are easy to modify. It requires a lot of information about the use and users of the product to take into account all these aspects.

Typically, user experiences are collected with consumer testing during the design phase or from the first-hand users. In circular economy, there may be several users for a single product, which increases the amount of available user experiences radically. This is still a mostly unutilised source of information; even though, some systems have been launched that include the collection and sharing of user experiences.

To get user experience information beyond the first-hand users presumes tracking the subsequent users or common systems in which users can share their experiences. It is more likely to get information if it is specifically asked from the known users of the product, compared to the spontaneous sharing of experiences in a common system, except if the experiences are extremely bad. Campaigns and incentives may be used to boost the collection of information from users. The user experiences could be collected also when the used textiles are collected for reuse, remanufacturing or recycling.

Developed sensor and ICT technologies enable the collection of data concerning conditions of use and the condition of a product directly during the use without asking it from the user. This is widely used in many other more complicated products than textiles. Smart clothing applying sensor technology is used to support the user in certain special applications, for example, fire fighters to control the heat load or workers to identify dangerous carbon dioxide level in their working environment. However, similar technologies could be used to collect data for product development, too. Embedding such technology in the textile, would enable the data collection during the whole life of the product.

To support the sustainable use and cycling of the product, guidance for the care, repair, circulating and recycling should be provided for the user. The challenge is, how to keep all this information available even for the first-hand user in the course of time, and especially for the subsequent users.

7.4 Standardization, Generic Agreements and Regulation

Standardization of information management would be required, in order to enable better transparency and wider availability of textile product information. The current situation, where the needed information needs to be especially asked from different stakeholder does not enable effective sharing and utilization of data, and forms one bottleneck in textile circular economy. On the other hand, it would not be reasonable to expect that all data concerning different textile product needed by different actors in circular economy would be collected in one single database. Standardization of data sharing interface between different databases and data management systems is especially needed to enable the digital transfer of information. This includes both the sharing protocols and information content standardization – including the product item coding. Currently available services and systems for textile information management are not well prepared for data sharing and communication with other data management systems. If standard interface or reliable conversion systems can be built between different data bases, it would open up plenty of new opportunities to utilise product information and even trade it.

Product identifiers would require a (global) standard determining how to formulate a unique product item code. This would make it much easier for different actors to utilise an identifier. There are some available services, which provide unique codes (and tags) when their system is used, but a global standard for this purpose is not available.

Another important aspect to be commonly agreed on is, what information should be collected and shared by whom and for what purpose and with which users. One limitation to the sharing of information between different parties is the fear that they lose the competitive edge in competition by sharing information. Not all information needs to be open for everyone and to be free, but a common agreement on what kind of information sharing is required to support textile circular economy would substantially promote information sharing that would be more open. The agreement could be made voluntarily between the different actors in textile circular economy. However, it is quite unlikely that such an extensive agreement could be made on voluntary basis, because the number and quality of actors in textile circular economy is so enormous. Therefore, legislation probably would be required to forward information sharing if noticeable progress is wanted. In EU, there already exist legislation to protect consumers rights to get information about the product before purchasing (e.g. Directive 2011/83/EU[18]) and the Circular Economy Action Plan[15] includes several planned actions to revise EU legislation concerning consumers' and public buyer's rights to get information supporting circular economy. Information sharing between companies has not been greatly regulated and that can be politically a much more difficult issue even though promoting circular economy has high priority in EU.

There are standards and standardization activities related to product data and its management:

- The Global Traceability Standard[19] by GS1 (ratified in 2017) "*defines a minimum set of traceability requirements within business processes to achieve full chain traceability, independent of any technology. It outlines a common framework to build a traceability system using other GS1 standards – such as barcodes, data carriers, eCom and EPCIS (e.g. RFID tag). This standard allows an end-to-end traceability system, linking the flow of information to physical products.*"
- The Circularity Dataset Initiative[20] aims to develop an industry standard at European level that provides a regulated framework for circular data on products throughout the whole value chain, from raw materials to finished products, from the use phase to recycling.
- A guide to Environmental & Social Compliance by Textile Standards & Legislation[21] is a collection of sustainability related textile standards, which also include information related guidance and standardization.

7.5 Information Security, Reliability and Privacy

The criticality of the correctness and accuracy of information varies depending on what the information is used for. Naturally, the information that is known to be correct is the only certainly useful information. Use of uncertain information is always a risk. If the incorrectness of information may lead to severe

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[18] https://eur-lex.europa.eu/eli/dir/2011/83/oj

[19] GS1 Global Traceability Standard. GS1's framework for the design of interoperable traceability systems for supply chains https://www.gs1.org/standards/gs1-global-traceability-standard, and guide https://www.gs1.org/standards/traceability/how-traceability-standards-work

[20] Product Circularity Data Sheet, Creating a digital circularity fingerprint for products, https://pcds.lu/

[21] Textile Standards & Legislation. MCL News & Media and the European Outdoor Group. https://www.textilestandards.com/

consequences, the trustworthiness of information source or the validity of the information should be especially ensured.

The consequences of using incorrect information varies a lot because of the wide variety of information and its usage. For example, providing too positive sustainability information may polish the image of the actor or product in the short term but it may ruin the reputation when the fraud or ignorance is revealed. Probably, there are no immediate effects on the use of the product when such misinformation is used. On a wider scope, sharing such misinformation hinders transfer to sustainable economy in two ways: 1) it tempts the wrong decisions, and 2) it weakens trust in sustainable economy and causes confusion. Thus, the transparency and reliability of sustainability information is essential for the whole circular economy. On the other hand, wrong or missing care instructions may cause concrete immediate problems damaging the product. Moreover, wrong or missing material information probably cause problems in or prevents recycling.

Availability and validity of sustainability related information is the hot topic and great challenge especially for textile circular economy. Circular economy has also highlighted the importance of information about the material and chemical content of the textile products. Ownership and authenticity are not necessarily generally the most topical issues concerning textile products, but circular economy emphasize the use of quality higher value products, which are usually also recognized brands. In this context, authenticity of the product is topical information. The true ownership is also a specific issue for circulating products - especially concerning the more expensive ones. There are technical solutions to ensure the authenticity and ownership information. These solutions use, for example, a block chain technology. The same technology can be used to ensure the traceability and invariance of information.

There can be several reasons why the information is wrong. These include ignorance, mistakes, technical failures, changes in product, dressing up, slandering and even a deliberate aim to cause harm. Product evaluations by users are, for example, susceptible for bias.

Technology enables solutions for tracing products, automatic data collection and getting ownership information. When developing and using such solutions, it is utterly important to take care of information security and privacy. In EU, General Data Protection Regulation (GDPR)[22] "*protects fundamental rights and freedoms of natural persons and in particular their right to the protection of personal data*". For example, the collection and storing personal of data requires the consent for one or more specific purposes from the person themselves (if the is not any specific legal purpose to collect and use such data). Personal data means any data, which identifies a (natural) person and the data which is linked to this identifiable person (directly or indirectly). It should not be possible to use the product identifier as a route to other information systems including personal data, either. As long as such personal data is not collected and stored, information management is on the safe side concerning the personal data protection. When there is use for personal data and such information is collected, it is vitally important to take care of information security. This is not only because of legal requirements, but also because the trust for the system is essential for getting the data. Similarly, the confidential data from any company should be appropriately used and secured in order to get access to such information. Trust building is an important part of building such an information management system, which involve multiple information providers.

7.6 System Dynamic Modelling of Data Utilization in Textile Circular Economy

System dynamic (SD) model for data utilization in textile circular economy describes what advance, and, in contrary, what hinders the exploitation of data; what are the implications of use and non-use of data (Figure 61).

[22] Complete guide to GDPR compliance https://gdpr.eu/

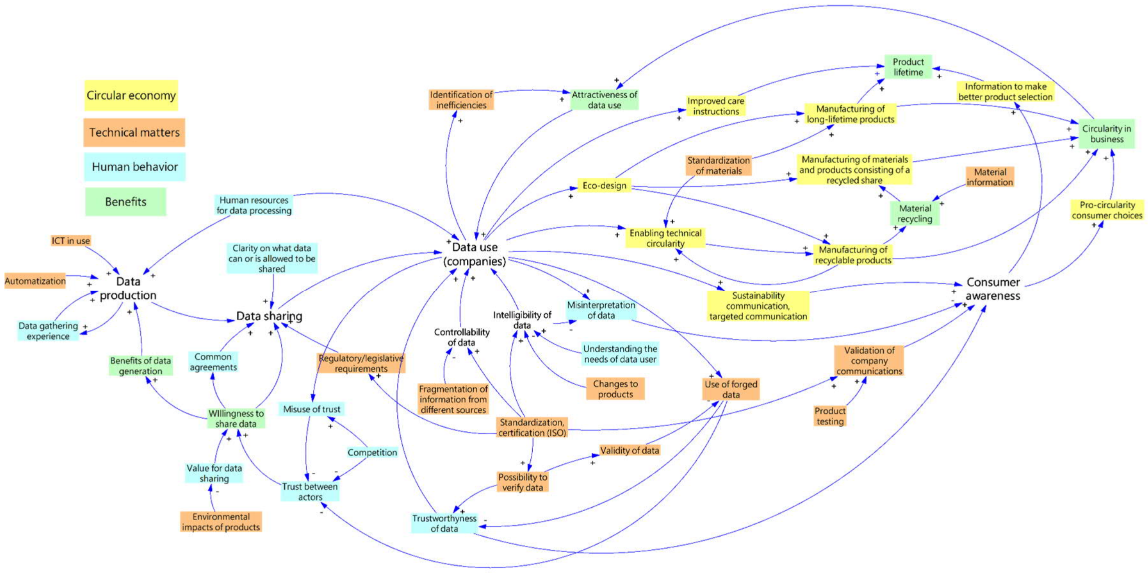


Figure 61 System dynamic model for data utilization in textile circular economy. Image available online be in https://telaketju.turkuamk.fi/uploads/2021/08/c1668a0d-telaketju-cld-eng-220321.png

The model includes six key activities concerning data. These include *Data production*, *Data sharing*, *Data use (companies)*, *Controllability of data*, *Intelligibility of data*, and *Consumer awareness*. The factors related to these key activities are grouped into four categories 1) *Circular economy* (activities and issues that lead to circularity), 2) *Human behaviour*, 3) *Technical matters*, and 4) *Benefits*.

The model can be used to identify and understand the challenges of information flow and the opportunities to improve information effectiveness, and the value that can be generated though data utilization. The most valuable outcome from the model is revealed positive and negative feedback loops that were illustrated based on the analysis of data.

An example of a positive feedback loop is presented in Figure 62. It shows that a) *Data use* for b) *Sustainability communications* raising c) *Consumers awareness* has a positive effect to d) *Pro-circularity consumer choices* improving e) *Circularity in business* and, further, improving f) *Attractiveness of data use*, which increase a) *Data use* (thus closing the loop).

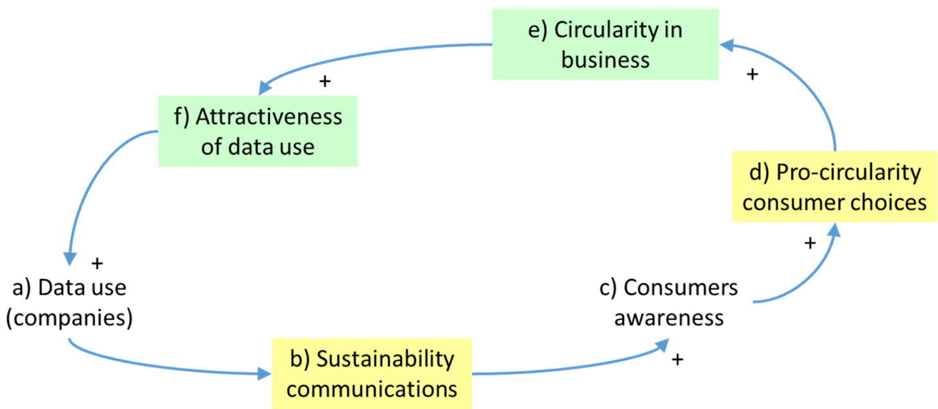


Figure 62 An example of a positive feedback loop in the System dynamic model for data utilization in textile circular economy

An example of a negative feedback loop is presented in Figure 63. It shows that a) *Data use* is away that is b) *Misuse of trust* decrease the c) *Trust between actors*, which, in turn, have a negative effect to d) *Willingness to share data* and, further, reduce e) *Data sharing*. Reduced sharing of data reduces opportunities to a) *Data use* - both the correct and misuse (thus closing the loop). Tight f) *Competition* tempts for b) *Misuse of trust*, and have an additional negative effect on c) *Trust between actors* and d) *Willingness to share data*.

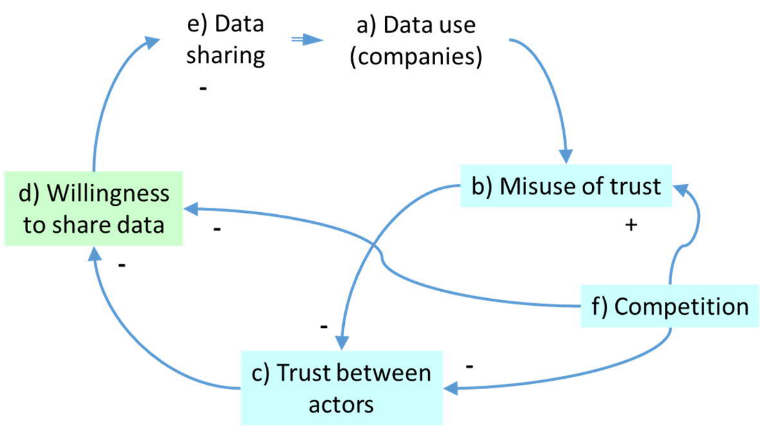


Figure 63 An example of a negative feedback loop the System dynamic model for data utilization in textile circular economy

Although the model opened up crucial insights about the dynamics of the data sharing in textile circular economy, it must be noted that the application of the SD modelling for the data utilization in the textile circular economy was a first trial in the project. Thus, its further development, application and analysis is needed to better understand the benefits and insights that the SD modelling can provide in researching the role of data in textile circular economy.

The main insights and data for the model were collected in two workshops where companies and researchers of the project were present. Experts of system dynamics modelling lead the workshops and created the model. Model has been published in https://telaketju.turkuamk.fi/uploads/2021/08/c1668a0d-telaketju-cld-eng-220321.png

8 Overview of Project Outcome, Impacts and Future

This section focuses on an overall evaluation of project and our views on the future. Chapter 8.1 composes on a comparison of the expectation and outcome of the project, and Chapter 8.2 of feedback given by project participants. Chapter 8.3 contains the Telaketju vision for 2035 and road-map how the get there.

8.1 Comparison of Expectations and Outcome of the Project

The overall goal of the Telaketju 2 project was to build business opportunities for Finnish companies in the circular economy of textiles including both novel circular business models, as well as business related to textile recycling. The project and its research questions were planned on the base of needs of the Telaketju ecosystem and participating companies.

In order to achieve this goal, we set eleven targets and respective expectations for results and outcome. These eleven targets (freely translated from Finnish) and related expectations, including comments related to the achievement of each target, are summarized in Table 17. When we compare expectations and outcome of the project we can see that project has been successful. It can be concluded that all targets were achieved, and participating organizations have given positive feedback from the project.

Table 17 Eleven targets and specific result and outcome expectations used in evaluation of success of the project

Target		Specific results and/or outcome (***achievement** <u>ok</u> **or as*** <u>**actual**</u>/<u>targeted</u> ***if applicable***)
1	Widen co-operation and networks of participating organizations nationally and internationally	Increased national networking within events (***3***/*2*) and direct contacts with individuals (>***200***/*200*) and companies (***tens***/*5*). International networking: companies contacted (***tens***/*10*), events organized (***8***/*2*) and events participated (>***20***/*4*) Scientific and technical publications (>***10***/*8*)
2	Create visions and networks for participating companies to implement novel business models	Increasing knowledge for companies to applied by providing a digital map about business opportunities (***ok***) and organizing hackathons, innovation sessions and/or living labs (***3***/***2***)
3	Create understanding of the effect of product design on sustainability and economically viable product design	Guidebook to be design process available for participants (***ok***)
4	Create basic knowledge on information based solutions in textile circularity	Knowledge made available to partners (***ok***)
5	Find sustainable, recycled and bio-based raw material options for textile manufacturing to replace virgin and/or synthetic ones	Sustainable materials reviews (***4***/*2*)

6	Improve quality of recycled textile fractions (via building concept for processes and developing classification), and, thus, support business opportunities around textile recycling	Concept for collecting and sorting (***ok***) Technical solutions for identification and sorting (***ok***) Initial classification system for textile waste (***ok***) Update of recycling costs model (***ok***) Market review (***ok***)
7	View sustainability of business developed in the network from environmental, social and economic point of views	Information about LCA calculation tools (***ok***) Review of social aspects of textile recycling in Finland (***ok***)
8	Test feasibility and co-operation possibilities related to novel business models using quick trials.	Carry out quick trials (***5***/*3*)
9	Demonstrate textile recycling with wide range of materials, processes and technologies	Carry out demonstrations (***at least 36***/*15*)
10	Produce information of consumer attitudes on circular solutions, and enhance business opportunities in this field via participating consumer communication activities	Consumer attitudes towards business models and recycling via consumer study (***ok***) Active consumer communication via • social media (*followers in Facebook* ***approx. 2300****/3000 and Instagram >****1000****/800*) • blogs posts (***at least 40***/*15*) • web page (*>****33000 session****/25000*)
11	Support further building of the ecosystem and, thus, ensure wide dissemination and impact of research results	Stronger circular ecosystem in Finland by making road-map (***ok***) and evaluation of export potential (***ok***)

8.2 Impact in Partner Organizations

The companies involved in the Telaketju 2 BF project have evaluated their feelings on the project in general as well its impacts.

8.2.1 Impact of Company Projects

Image Wear

The project has had a major impact on our thinking on circular economy. We have educated all our employees on the basic elements of circular economy and increased the understanding on the changes we must do to be able to survive in the textile industry. The project group has learned from all the seminars and has spread the word by linking the webinars to those who need it within our organization.

We participated in the *Spanish demo* where we sent used work wear to LSJH and then to the project partner in Spain. The fabric received was made into an apron and shirt and is now tested by our customer (see Figure 64a). We are comparing the usability and strength between a virgin material apron and recycled material apron. LAB has also tested the material in their laboratories and the test results looked good.

In the value chain workshop, we explored different processes for work wear as a service with the assistance from Turku AMK. One student made a quick study on how other companies have dealt with the problem of changing embroidered logos or nametags when the garments go from one customer to another. Benchmarking showed that there are no good solutions yet, but some pilot projects are interesting.

VTT has used our side-flow materials from our cutting process (paper and plastic film) to make different composite materials and the results look good. We have tested successfully with Sideflow Oy a model for our surplus material, where Sideflow finds collaboration partners and sells our production surplus fabrics to those who could use them in their production.

We have been a case example in two design courses at LAB; designing a garment from recycled materials and design a work jacked for circular economy.

We got started with our own Tracking tool (digital passport) development and will continue with that. In the beginning, we can track our production facilities and fabric producers and we are moving towards to model where we could track Image Wear work wear from the fibre manufacturing up to the end user and recycling (see Figure 64b).

Co-operation with other consortium members has been of great value for us. All the companies (and research partners) are facing the same problems and trying to find solutions. Unfortunately, the Covid-19 pandemic made it impossible to travel abroad or even here in Finland, which made informal discussions impossible. However, the new collaboration platforms that the research partners brought into the meetings and workshops were great and helped to change informal information.

a) 

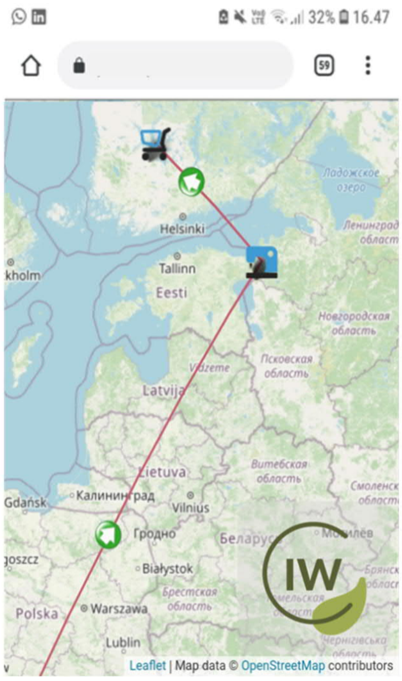
b) 

Figure 64 Image Wear result examples: a) Apron made of recycled materials and b) Tracking tool

Lounais-Suomen Jätehuolto

Since the beginning, LSJH has been involved in building of the Telaketju network. Initially, we only had one picture (see Figure 3), with which we toured in seminars and meetings to share our common idea of building a textile circular economy network and ecosystem in Finland.

For the first three years LSJH focused on collection and sorting. The work was done with universities, charity organizations, employment organizations and other municipal waste management companies. The ever-expanding Telaketju network supported the development work, and the shared vision guided the journey.

However, we also realised that Finland lacked equipment and companies that could process end-of-life textiles into recycled raw material. There was a missing piece in the value chain, which could enable companies to develop their products and processes for using recycled fibres as raw material.

In the Telaketju 2BF project, LSJH participated with its own loan project to invest in a pilot processing line for end-of-life textiles, which would process post-consumer textiles. The process was anything but simple. This had never been done before, so there was no benchmark to learn from.

First of all we did not find suitable premises for the machinery. Fortunately, and happily, we heard that the companies that had found each other in the Telaketju network had also started to solve the issue on the B2B sector and Rester Oy had been established. They had construction plans and we combined our efforts and plans and instead of planning one line, we started planning to place two lines under the same roof at the Green Field Hub in Paimio (see Figure 65).

Figure 65 Green Field Hub in Paimio

The value chain was replenished with the missing piece, and research was carried out in the public part of the Telaketju BF2 project to balance investment and risk-taking. LSJH benefited from the consumer survey conducted in the project, which received encouraging feedback from residents and consumers. This confirmed that the direction of our development plans and the work we are doing in Telaketju is the right one.

During the project, we were able to outline, together with the municipal waste management companies, a nationwide collection concept and a collection expansion plan. In the webinar series of the project, we were able to present our ideas to both Finnish and international audiences.

The communications, dissemination and linking the actors together has been very important for LSJH to success so far. Telaketju blogs, webinars, communication for followers on webpage, Facebook and Instagram etc. has have a major support for the whole development work. International cooperation events have been very important from the point of view of exchanging information and learning and finding new partners. Without this joint effort, many people and companies would certainly not know about us and about the work we are doing.

Without Telaketju projects and the network built around it Finland might not be one of the countries mentioned in STJM´s and Euratex´s ReHub initiative. Telaketju also identified the need for a joint topical forum, which Finnish Textile and Fashion established. For the second time, there were almost 200 participants in the forum from Finland alone, which was fantastic. During the project, we were able to grow the Telaketju network and create a permanent forum that brings together parties and projects working for the circular economy of textiles.

The project also included a lot of research on recycling solutions, and we were actively involved in implementing the Spanish demo. Unfortunately, due to the Covid-19 virus, the study trip was not organized, but we were still able to finish the demo virtually.

A total of 10,000 kg of end-of-life textiles were collected from seven different companies. The textiles were sorted, pre-processed and part of them were also identified with NIR scanner (also develop in one of the Telaketju projects earlier) with the help of Turku University of Applied Sciences students.

After the pre-treatment in Finland, all the textiles were sent to Spain for tearing and yarn and fabric production. Various experiments were performed on the fibres, yarn and fabric in Finland by VTT, LAB University and some other partners. This provided a new information and understanding of the potential of the future refinement line and the textiles as a raw materials.

Important work was also done with material identification. LAB universities carried out identification tests and compared a few different devices. There is still a lot of work to be done in quality assurance of sorting. During the project, the understanding of the opportunities and challenges of NIR technology increased.

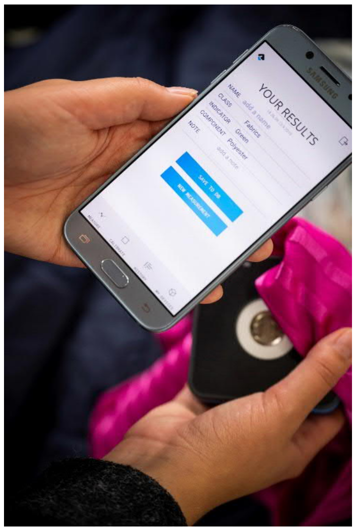
a)  b) 

Figure 66 a) Textile sorting at LSJH, and b) hand held NIR scanner

Statements on certificates, modelling of collection and sorting, as well as market surveys were important and relevant to LSJH's future plans. Without the support of the projects, network, the public research and experimentation, we would not be here today. All the work done give us the solid base for planning a refinement plant to Topinpuisto circular economy centre, which will cover the capacity needed for processing post-consumer textiles of Finland and also for some of the Baltic Sea countries. We have been able to take forward a nationally collection and sorting system. We are also able to look for utilization solutions and quality assurance methods together with universities, research institutes, Rester Oy and many other Telaketju network members.

We hope that funding will be found for the work in the future as well, because now when we will have the refinement lines up and running in summer 2021, there is still a lot of research and development to do. We want to see Finland be one of the recycling hub´s of Europe, find the best possible recovery solutions for as many textile streams as possible and that Finland's circular economy of textiles ecosystem and network become even stronger and remain unified.

Pure Waste Textiles

Taking an active role in Telaketju 2 project was a natural next step for us as we made remarkable findings and obtained promising results in the first project (Telaketju). Our expectations were met also during this second project. We will describe the impacts of the Telaketju 2 project in the four categories below.

First of all, we cannot emphasize enough the power that comes from the community. By community, in this case, we mean the project consortium. There has been so much exchange of information, opinions, and ideas that we would not have been able to accomplish anything without the help and inspiration of the people and organizations involved. Networking has enabled the formation of the ecosystem in Finland and new projects are already being planned.

Secondly, there are several R&D-related results that were enabled by this project. We were able to develop and test both knitted and woven recycled fabrics with new yarn counts. Also, we researched the qualities of both CO/PES and PES/CO fabrics (made from post-consumer fibres) and obtained positive results for opening and spinning. Generally, these kinds of fibre mixes are considered to be problematic in the recycling process. The R&D results that were developed in Telaketju have been commercialized so we are hoping to do the same for these developments as well.

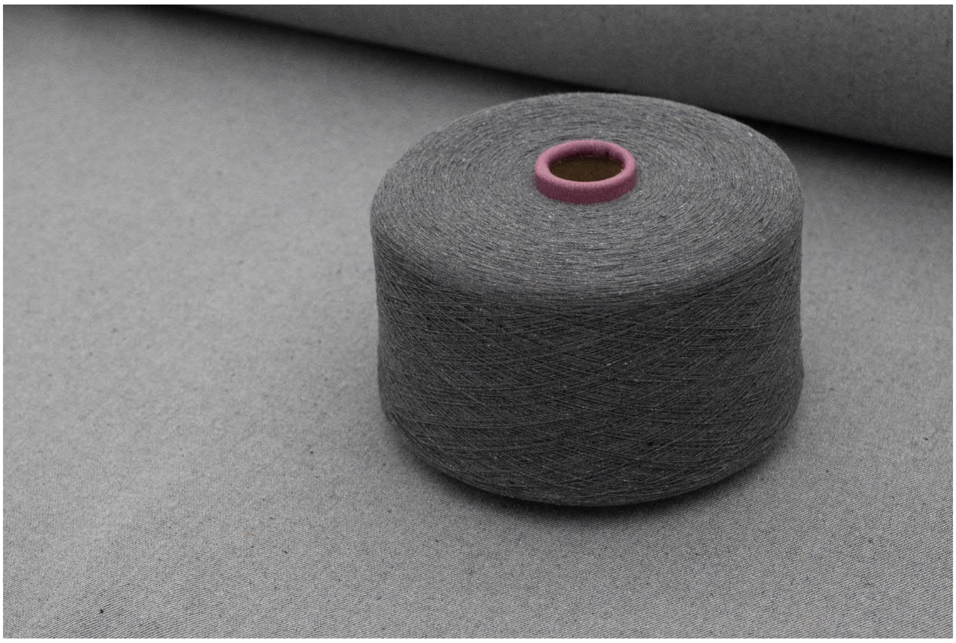


Figure 67 Mechanically recycled material

Third, we were also able to test a new business model and research the possibilities of on-demand production in Finland. These kinds of services and models are in a key role when it comes to transforming the linear way of operating into the new circular economy in the textile industry. In addition, we researched the possibilities of tracing pre-consumer textile waste because being 100% sure of the source and being able to communicate it is crucial for our ambition to be as transparent as possible.

Fourth and one of the most important impacts has been on the research of the possibilities and feasibility of a spinning mill in Finland. We have found that the ecosystem that has developed around the circular economy of the Finnish textile industry is active and full of great potential. New business models, recycling technologies, and recycled fibres are here already. However, it is missing a piece that would bind it all together and that piece is a spinning mill.

We are very pleased with the outcome of this project and are looking forward to new upcoming projects and the potential spinning mill in Finland.

Touchpoint

The biggest impact of the project has been the growth of an international network and knowhow of circular possibilities. This has risen awareness inside the company / Touchpoint team and further more we have been able to share our experiences with wider audience including our business partners, clients and other network. Our action points on development have focused on material strategy and closed loop service model where we have also achieved competitive edge. Within our work packages we have been consistent in building our service design to support our strategic goals. This has included LCA calculations and reporting in order to give transparency and informational tools for our clients' benefit.

Covid 19 has naturally been slowing down work wear sales in the service sector, so our financial growth plans have not come true in full, but on an informational aspect we have risen to a new level regarding circular materials and end-of-life textile services. Our activity in the project and earning the forerunner role has strengthened our position with the network of our supplier partners as we have challenged existing, traditional work wear culture.

As the most remarkable result within our project we have accelerated our "next generation" plans to activate waste textile handling by grounding a new company, Rester Ltd, for this purpose. This is a significant step towards circularity, while it will also, as a consequence, hopefully re-activate and bring new growth to the whole textile industry in Finland. This has also been a great example of collaboration between municipal and private owned equity, as Rester and LSJH have been building this facility together side by side (Figure 68).

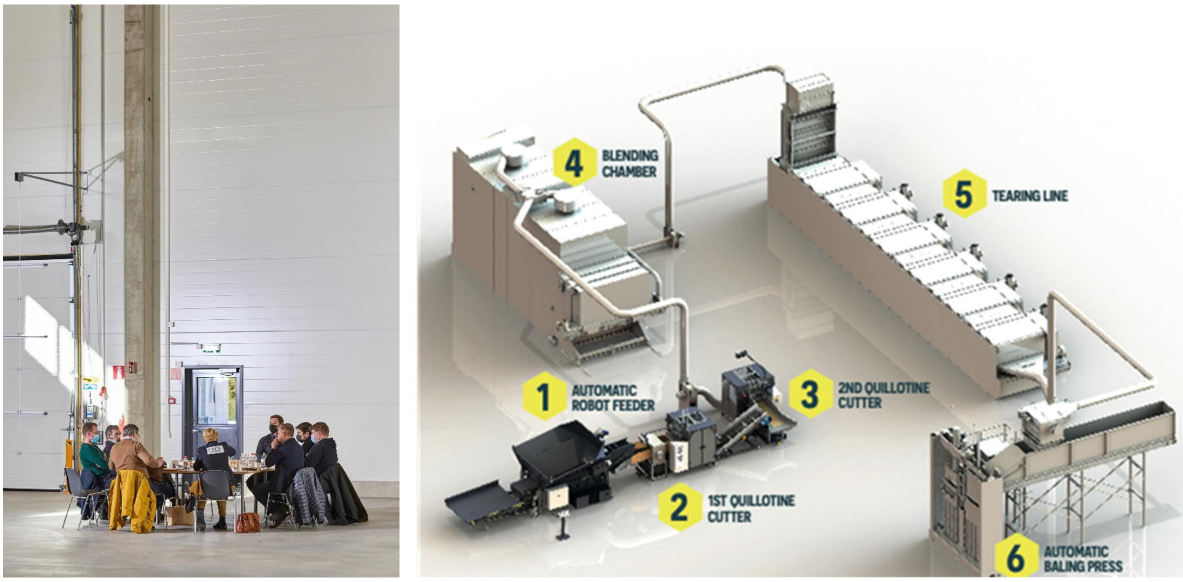


Figure 68 Rester site in Paimio: consignment meeting of the plant and Laroche machinery to be installed

8.2.2 Impact in Companies who Co-Funded the Project

Aijuu

The aim of Aijuu concerning Telaketju 2 was to learn, network and to find new business possibilities. Aijuu abjured their own unprofitable Tekstiilikierrätys.fi- service during the project and focused more on learning and moving the learned things to other operations, especially business education directed to children and youth. With the project Aijuu strongly raised their know-how and knowledge on circular economy. This was the biggest benefit of the project for Aijuu that they can benefit on many different ways, also in lecturing various adult groups.

During the project, Aijuu`s network associated with textile circular economy increased as desired. Brightening the strategies, it moved Aijuus`s business model to a more pedagogic and entrepreneurship education way, and education, consulting and project management related to those. Benefits of these from the project shows currently especially in content and understanding of circularity field. Paucity of time resources Aijuu could not be part of the different divisions of working as much as they wanted and because of that they see that they could benefit more their own know-how, rather than other participants know-how.

Understanding and know-how of circularity should be continuously more and more important role in every business but also in entrepreneurship education. With the learned things from Telaketju 2 Aijuu will pursue also in the future to raise circularity and sustainability forward in every activity.

Black Moda

Participation in Telaketju has widely increased our knowledge and networks giving us subjects for thought for the future.

Globe Hope

The Telaketju project has increased our understanding of the market and trends of the market. We have become more aware of international business in this field during the project. In addition, the research of VTT and its possibilities to Finnish companies have become clearer during project.

The project has increased the company`s focus on Zero Waste project which concentrate on the B2B process effectivity of end-of-life textiles recycling. We have raised our clientele and done new openings to different branches. The know-how of our staff has increased. Client pilots has also been executed during project. Requirements of business has improved during project. We have increased our collaboration network and converged with operators of circular economy ecosystem in different segments.

Infinited Fiber Company

Infinited Fiber Company is looking for a location in Finland to build a flagship factory to produce its unique, regenerated textile fibres for the global market. Infinited Fiber Company will decide on the location by September. The planned flagship factory will have an annual capacity of 30,000 metric tons/annum and will use post-consumer textile waste as feedstock.

The plant’s entire output is intended for export. Infinited Fiber Company is currently negotiating offtake agreements with several global fashion and textile brands and believes that agreements will be in place before the end of 2021, securing the factory’s entire output capacity for several years. The total investments for setting up the flagship plant are estimated at around 220 million euros. Infinited Fiber Company expects its currently ongoing evaluation into financing options for the plant to be completed soon. The plant is expected to be operational in 2024.

Telaketju project has helped IFC to come to this proud conclusion by providing a great deal of vital information on textile waste amounts and composition available. More over, it is important has been that Telaketju has created a basis of the textile recycling network of companies and partnering enabling next investment planning and preliminary sourcing opportunities.

Kehräämö Mustalammas

The Telaketju2 project has helped The Blacksheep woollen mill to build our business to become responsible. It has given us knowledge of product planning and marketing. During the Telaketju2 time, we have created new products and met new cooperation partners. The Telaketju2 project gave us good a foundation for future working.

Coveross

What were the key benefits of the Telaketju 2 for our business?

- New knowledge of circular textiles and their ecosystem.
- New potential business and RDI partners.
- Positive impact on brand.

What were the key learnings?

- Circular requirements effect the whole value chain from raw materials to design and from certifications to brand.
- Collaboration is very important.
- It is possible to create new business from circular textiles economy.
- Communications to consumers and clients crucial for success. Not easy to explain why recycled is a better choice or more sustainable.
- ROI on sustainable technology is not so easy.
- Sustainable products are difficult to sell without good samples and scale up production calculations.

How did this influence the company's future strategy?

- Replacement of used non-sustainable substances in the testing phase.
- New upcycling technology in the planning phase.
- Finishing with recycled materials ongoing for textile products.

Did this have an impact on sales?

- Not in Europe yet, but in Japan, yes, due to a positive brand impact and media attention.

Did you find new partners because of the program?

- In Finland, yes, for possible new business. Also in Japan, yes, due to the increased sustainable brand image of Coveross.

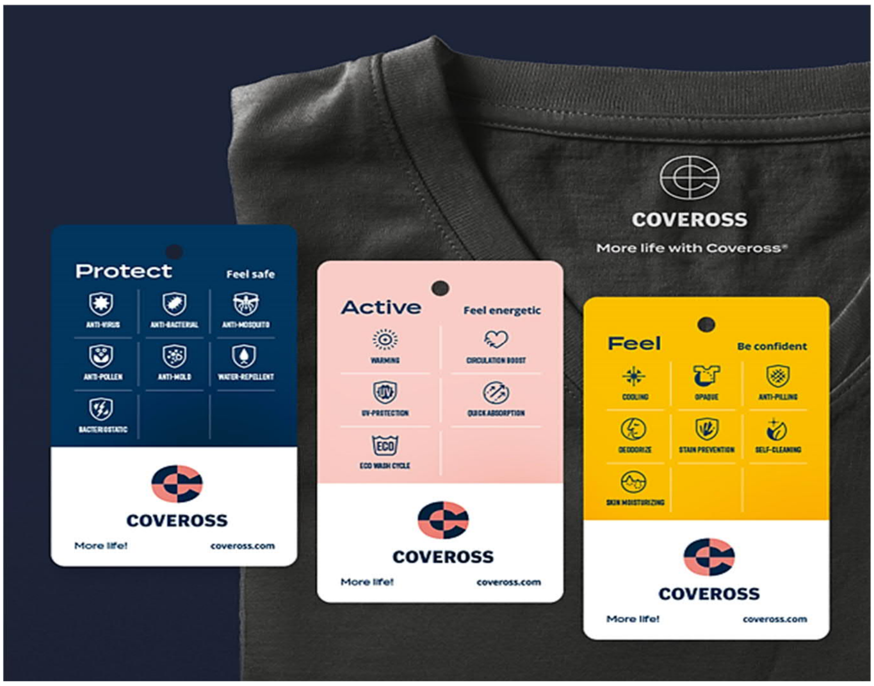


Figure 69 More life with Coveross

Mirka

During the Telaketju project Mirka was able to participate in several demos and see what our waste could be turned into. Our textile waste was sent to a European company to open it back to fibres. Sadly, we were not able to participate in the production and were not able to see what affects the process. But still we were able to recognize that this could be an interesting way to turn our waste back to useful raw material.

We also participated in the demo where our waste material was pelleted, and then moulded into a tensile strength testing rod. We found out that our textile dyes were affecting this process. Still the end product had good tensile properties, so it is a really good way to recycle our waste and needs to be further developed.

During the Telaketju project, Mirka has been able to network with Finnish textile companies which has been invaluable as otherwise we have not been in much contact with such a broad range of textile companies. We were able to learn about textile circular economy through many interesting webinars and management team meetings.

Nosh

Participation in the Telaketju project has been important in designing our company's own circular model. We have received new and up-to-date information on textile reuse. Through Telaketju we have also networked with other companies in the industry. The topics covered in Telaketju, example cases from companies and joined discussions in the meetings have helped our company to understand what kind of business opportunities our test project can have in the future. By participating in the *Spanish demo*, we had the opportunity to concretize an idea of a new material made from old NOSH clothing. Of course the model requires development, but we believe that the implemented demo worked very well. It also proved that the quality of our clothes is very high. The high quality of the raw material (NOSH clothing) guarantees that it is possible to create new material and also raises the quality of the final material.

The opening of the fibre was successful, produced a new kind of material and gave us additional ideas for textile sorting. The textiles we sent to Spain contained textiles that were not suitable for selling. The demo project showed that we could diversify the end product by sorting the textiles by colours and materials. This could allow us to have several different material qualities as well as the colours of fabric without dyeing processes.

Of the demo fabric, we designed a zero waste bag, for which we are currently planning marketing measures. The product enables us to increase our customers' awareness of our development work in responsible production. After the travel restrictions caused by the corona pandemic will be released, we want to explore more widely the opportunities offered by the project partner in Spain. Different material options could allow the design of a completely new lifestyle product range. Such a collection could include storage bags, tote bags, pouches, aprons and other products that require a thicker woven fabric and differ from our normal knitted materials. The range of materials available from our opened fibre is therefore not yet mapped, but we believe that there are opportunities to make a wide variety of materials suitable for lifestyle products.

One of our responsibility goals is to build our own circular economy model for our textiles by 2023. Our intention is to find a model to which we can direct the non-marketable textiles in a commercially viable manner. The sorting of textiles required by the model also opens up new opportunities to organize alongside some kind of sales channel for those products which would still allow use and resale as a second-hand product.

Paptic

The project has largely helped us to evaluate the possibilities that textile circular economy has brought to us regarding of our raw-material choices in the future. The project answered our needs well.

Reima

Reima has benefitted from the opportunity to test the recycling of the innovative monomaterial jacket, Voyager, at a small scale, as well as from the networking among and beyond the consortium. Additionally, the various consumer insights generated throughout the project will be useful for planning future circular economy projects within the company.

Sideflow

The project has been, in every way, interesting and very necessary for promoting Finnish, Nordic and global circularity. It has been great to follow how a big and significant group has been working seamlessly towards a common objective, for a resource wise future. Especially it has given a possibility to get to know companies that are interested in circularity that possibly otherwise would not get to know so closely. Throughout the project we have also carried out collaboration openings with companies and education establishments. There have been interesting parts of research in the project that have helped us to improve services to certain direction. We get to be proud that with successful cooperating mentality we have achieved a lot of good.

Vaatepuu

The business requirements of Vaatepuu increased with the Telaketju project. Our understanding of the textile industry in its entirety expanded and our own place in it started to grow clearer. We got a lot of current information and we created lasting networks that help us also in the future to keep up with current issues. We found new business cooperation partners whose products now circle in the loaning facilities. We also found a business whom with we have together planned non-traditional business activities concerning textile circular economy.

Valmet

Valmet Fabric's Unit participation in the Telaketju 2 project has increased our knowledge of circular economy and ecosystems among the textile industry in Finland. In the public research done surveys concerning especially bio-based fibres and chemicals and also textile as a source of microplastics have given us new information, not forgetting other published material as well.

Learnings from the LCA work stream supported us in making the life cycle analysis of our own products. By networking with other participant companies and the people in Telaketju 2, we have ained good contacts, maybe possible partners in the future concerning recycling. Some evaluation of Fabrics side stream materials utilization from the production has been considered with some companies involved in Telaketju 2. With the new Modular mixer (MODIX) technology by VTT our forming, pressing and drying fabrics were compacted and compounded nicely without any problems although the fabrics consist of different polymer materials. This new technology has given us new ideas for the future thinking of recycling possibilities of used fabrics from paper industry.

Vileda/Freudenberg

The Telaketju project has holistically built a picture of the elements of textile circularity and is most helpful in bringing the sustainability message further. Networking with different stakeholders as well as student contacts have opened new opportunities and ways of thinking. New business models are being scanned and will be developed within the company based on information and knowledge collected from the studies in the Telaketju project. The trials done in demos set a starting point for the next studies and actions to circulate used products.

8.2.3 Other Organizations

Fida

Fida has a vested interest in the future of textile recycling in Finland. Because we sort a large amount of clothing per year (approximately 1500 tons), we deal with a significant amount of textile waste. Throughout the Telaketju project, Fida has been able to gain valuable insight about the future of Finnish textile recycling, and to share from our own experience and methodology in textile collection and sorting on a larger scale. Fida's goal is to find long-term ecological and cost-effective channels for recycling otherwise unusable textiles. It is also important to us that, in the midst of new textile-waste legislation and practices, charity organizations are able to continue operating effectively in the second-hand textile market.

Nextiili-paja

In the Telaketju project, Nextiili has acted as an influencer, in collaboration with Tredu we have created sorting of recycled textiles as part of 15 academic credit parts of the degree of textile and fashion line basic examination.

We participate as a pilot in collaboration with Pirkanmaan jätehuolto and Lounais-Suomen jätehuolto to transfer textiles to a further refinement plant. We are sorting the textiles according to fibre fractions.

Pääkaupunkiseudun kierrätyskeskus

Pääkaupunkiseudun kierrätyskeskus wants to find more sustainable solutions for the utilisation of textile materials. The project has brought ideas and solutions to this. We together with HSY and LSJH, have achieved an operating model with which we can collect and deliver textiles that are unfit to reuse to material utilisation. During the first six months, we have delivered 165 tonnes of textiles to recycle. This practice pilot has taught us particular notices in our practical processes. Logistical processes are still relatively ineffective. Because of the length of Finland, the meaning of logistics cannot be highlighted enough.

At least mentally, it has been important for us to stay aware of what is happening in the circular economy of textiles and this project has been a fine channel to get national and international knowledge. Learned things have helped us to compose new business possibilities in this changing work environment. In addition, it has been important to take part of the vision and road map work in the reuse point of view. Participation has also strengthened our networks in some parts and in that way it creates better possibilities for project work in the future and helps us to specify our own status in textile circular economy. We have also been able to spread interesting information about Finnish textile circular economy in our own international networks.

SaimaanVirta ry

SaimaanVirta association has received the latest information from national plans for the collection and recycling of waste textiles and the possibilities of utilizing different recycled textile materials. The association has found partners and opportunities to develop its operations through partnerships.

Finnish Textile & Fashion

Telaketju has played an important role and done a valuable work by building a circular economy ecosystem around textiles. As a result of Telaketju, the awareness of the circular economy of textiles has increased in Finland. The topic is currently of interest to companies, financiers, and decision-makers. The Telaketju project has awoken knowledge and interest, several Finnish companies have boldly and open-mindedly tried out new circular solutions and business models. New companies have also emerged in the sector, and textile recycling is at the heart of their business.

The Telaketju has successfully built an ecosystem that promotes textile recycling, but it has also identified during the project the need to share information wider. As a result, Finnish Textile & Fashion launched a new circular textile information forum in autumn 2020. The aim of the event, which is held 3-4 times a year, is to bring together all those who are interested in the circularity of textiles and share the latest news on the subject to the widest possible audience at once. The events held so far have gathered around 200 participants each time.

During the Telaketju project, it became clear that the separate collection of textiles will start in Finland by 2023. Other countries across Europe are also preparing to start the separate collection of textiles by 2025. To prepare for this, Finnish Textile & Fashion, in co-operation with its four European sister organizations and the European textile industry association Euratex, launched an initiative to promote textile recycling through five recycling hubs. The aim of the initiative is to bring together textile collectors, processors, and manufacturers across Europe to find an economic viability and use for separately collected textile waste streams. With the ecosystem built in the Telaketju project and the international visibility, Finland would be a potential location for such a hub. However, we still need investments for the development of digital platforms, increasing the processing capacity for waste textiles and expanding research and development.

Verstas 247

Our perspective in the project has been in extending the life cycle of textiles by maintaining, mending and remodelling them, preserving and promoting the skills needed in these activities, and the role of the average person in the textile circular economy - not only as a consumer but also as an actor. In the project, we had a purpose - and money set aside - to communicate these contents and meanings. Then came the pandemic, and our money was spent on rent, so communication had to be forgotten. Despite this, we consider participating in the project to be a positive experience for our small start-up company. A little bit of visibility and some opportunities to highlight the perspective of the average person and the importance of maintenance, repair and renewal as part of the textile circular economy, as well as up-to-date knowledge and understanding of how the ecosystem is being built - knowledge of actors. We gained all of this.

8.3 Telaketju’s Vision and Road-Map for the Future

Telaketju Textile Circular Economy Vision 2035

Textile economy has become holistically sustainable, enabled by circular design, high quality materials, including novel bio-based fibres, on-demand and local production, and prolonged product lifecycle via servitization business models. Raised awareness has increased sustainable consumption and created markets for sustainable textiles, which has resulted in an emergence of profitable businesses that are environmentally and socially sustainable. Regulation has played a vital role in driving the sector towards circularity. Extensive access and availability of product data along the entire lifecycle, as well as in-between cycles has led to an incremental re-circulation of textiles reducing a need for primary raw materials.

Textile production is lean and demand-driven optimized by digital technologies and comprehensive sustainable management of the supply chain. Sorting technologies have developed to serve the sorting of reusable items as well as to produce (sufficiently) large volumes of textiles for different market demands, as well as several established recycling technologies are enabling textile-to-textile recycling.

In Finland, sustainable systems for textiles have been built based on voluntary actions that rely on Finnish regulation and support from actors such as ministries and public funders. The current system has been built before there were requirements from the EU (not based on the EPR system).

The vision 2035 for the textile economy is structured into five main themes that were selected based on the needs of the Telaketju consortium and focus of the Telaketju 2 research project.

1. Trends in consumption and regulation including global, European, and national aspects affecting circularity of textile in general
2. Textile products and production including used materials, design strategies for products and production aspects of textile
3. Business models of the textile sector focusing on changes and new models related to circular economy
4. Technologies related to sorting and recycling, including the availability of different kinds of recycled fibres
5. Information including, for example, material and product data, as well as the tracking and tracing of materials and products, and transparency of value chains

The following chapters introduce these themes. Introduction starts with the Vision for 2035 followed by description of main challenges of current (2021) situation. Next, we describe how to reach this vision i.e. identified actions, specifically research and development that are needed to achieve the vision, which is followed by listing the enablers and barriers. This introduction is by no means comprehensive, but contains information and ideas raised up in the Telaketju consortium.

Figure 70 Summary of Telaketju vision for 2035

8.3.1 Trends in Consumption and Regulation

Vision 2035

Increased awareness has elevated sustainable consumption and created markets for sustainable textiles. Products incorporate all lifecycle costs, including environmental & decent pay for workers. The consumption of textiles is conscious and has shifted from fast cycles to the ownership of timeless and durable products that last in use. The focus in the market is on lifestyle, comfort and functional textiles, which are gaining fashionability. A new way of designing textiles has created a robust standard in the market where companies compete for sustainable design, quality and lasting power of products and materials.

A fair price for textiles and the high quality of products means that the price of a textile product might be higher than it is in 2021. This in turn means that textile products are valued, and they are more taken care of and used efficiently. Design enabling multi-purpose and versatility of textiles with properties, such as modularity and possibility for easy adjustments based on needs, provides a longer-term value for the user justifying the risen cost. On the other hand, widely available renting and other types of textiles-as-a-service models ensure that textiles are also available with lower prices when needed.

Reuse, repairing and remaking are prioritized over new purchases and over recycling. Former retail shops have been complemented with second-hand sections and have become multipurpose spaces with services, also providing guidance and use of the facilities. There are also services for the lifetime extension of textile products. Social companies and non-profit organizations have determined roles in textile re-use business. Servitization models are applied across all parts of the value chains, from material acquisition to end-of-life of the textiles.

The application of certified recycled fibres (also as blends) is widely accepted and the new normal, hence use of 100 % virgin materials products are considered to be inappropriate. Consumers accept that there might be inconsistencies, for instance, in the colours or appearance of products due to use of secondary raw materials including recycled fabrics and fibres. The availability of recycling technologies is acknowledged and considered to be an important part of textile life, but does not justify excessive consumption. Next to each primary fibre type, there is a recycled fibre type (e.g. CO, r-CO), and recycled fibre markets have been merged with the virgin fibre markets.

EU regulation has changed the textile sector enabling sustainable production, use and the recirculation of textile products and materials. The regulation drives the design of textile products based on eco-design principles considering the entire lifecycles of textiles and has set tangible goals for the reuse, as well as supports textile service models and material recycling having no overlapping contradictory legislation. Furthermore, regulation prohibits the disposal of the unsold textiles. Separate collection of textile waste is an established practice and plays a vital role in replacing the use of primary materials.

EU Green Deal and public actors support circular solutions, for example, public procurement favours the renting and use of recycled materials. Separate collection of textile waste starts first in forerunner countries (e.g. Denmark, Italy, Finland) (2022-2023) and then in all of Europe (2025) making secondary materials available for use. Ambitious and concrete targets have been set for textiles that have been achieved on schedule. Set targets have increased the recirculation of textiles significantly in similar manner as targets for municipal and packaging waste (*European Commission*, n.d.). The implementation measures are supported by public incentives and regulatory measures. In Finland, textile waste flows are reported systematically and related statistics are available. Regulations related to waste status and end-of-waste processes are clarified; they are easy to interpret and apply in practice.

Present 2021 – main challenges

Textile consumption is mostly price oriented where quantity is preferred over quality. The price of textile products, especially textile materials is too low, which does not incentivize for their unwasteful use. Appreciation of sustainability and rising awareness on conscious and responsible textiles cannot yet be seen in the consumption behaviour of big masses. It has reached the attention of the textile sector and brands, but the supply of truly circular business models are still relatively rare. The EU's regulation has already prohibited the landfilling of textile waste, but it does not yet lead to the value preservation of materials and their true potential is to be tapped. There is only limited public incentives and support for voluntary measures for separate collection and recirculation of textiles.

How to reach the vision?

There is a systemic level change needed for shifting the attitudes towards textile consumption in which preowned textiles are not received as low-value consumables, instead accepted as valuable and sustainable alternative. This change is predominantly required in the upstream of the textile sector. The availability of business models supporting the reuse, repair and recycling models needs to emerge not only in the cities but also in the rural parts of the countries, which requires a novel type of integration in the system to ease up the circular consumption of textiles. In moving towards circularity, the textile sector, emerging businesses and novel business models need to take into account the patterns and habits of the textile consumption. In inclusive circular economy, collection and reuse operations should continue as part of the social enterprises and employment also in the future.

Personality, individuality and need for changing the textiles from time to time are essential elements in textile consumption and need to be considered while ensuring more sustainable use of textiles. At the same time, bringing sustainability into textile consumption also requires open mindness on behalf of the consumers. Perhaps with certain items in the wardrobe there can be more flexibility whenever desired item is not available at second hand or leasing stores.

Fulfilling the vision depends on ambitious goals to be set for the textile sector for sustainable use, reuse and recycling of textiles by the European Commission. From a regulatory point of view, there should be support and incentives for promoting reuse and repair activities. An obligation for sustainable public procurement is one of the most efficient ways of advancing the transition to a sustainable use of textiles; notably to choose the high quality and durability of procured products, reward low-impact manufacturing processes, favour products that are designed for longevity, from recycled or bio-based materials, and which can be recycled at the end of life.

European wide classification via standardization or certification should be taken into use to increase the use of secondary raw materials. The initiation of systemic recycling requires recycling infrastructure and returning missing parts of the production chain (e.g. yarn spinning and weaving) back to Europe, and this should be supported by public investment aid. Furthermore, circular transition requires support from regulatory players to rectify and clarify contradictory, overlapping and obscure regulations.

Enablers	Barriers
• Increase in consumer awareness • Widening of offering of re-use items and thus making comparison easier e.g. via the availability of digital information such as available sizes suggestions for alternative products • Second-hand items have proven durable and they are comfortable as starches and unfixed dyes has already been washed away • Getting familiar with and getting used to service models which are already available in sectors and for other types of goods • Consumers getting familiar and used to textile service models such as streaming movies and books. • Extended producer responsibility (EPR) could enable circular economy solutions depending on its contents • Lighter taxation for services, redesign, remaking and second hand businesses • Application of recycling and waste fees • Define agreed criteria to support Green Public Procurements • Launch large-scale action to educate designers and consumers on circularity in textiles • Fact-based analysis of labelling and actual environmental impact information in consumer decision making	• If finding and shopping of second hand items is more difficult and time consuming than purchasing new items; and if finding what you need from second hand market is unsure • Assuring cleanliness and hygiene of reused products • Acceptance of garments and shoes that come with the shape of previous users • How to pay rents with margin obtained with low value second hand items • Overlapping and contradicting legislation • EPR if implemented in a way that it gives an unfair advantage to exports over local textile industry and retail or if it prevents voluntary based operations • If EPR requires different rules that contradicts the existing system • Currently the price for sustainable products is higher than their competing counterparts

8.3.2 Textile Products and Production

Vision 2035

Holistic circular design thinking is generally deployed in the European textile sector. Textile products are safe and sustainable by design and they provide value for the user. Furthermore, the high quality of materials and products enable long-term use and reuse of products multiplying product cycles and ensures value-preserving material after recycling.

Novel bio-based and circular raw materials are widely used in textile production. New cellulose-based fibres have entered the markets in the early 2020s. These and other sustainably produced virgin fibres are used also as fibre blends with recycled fibres in order to ensure high quality and targeted properties. Use of mechanically recycled fibres increased in early 2020s, and chemically recycled fibres followed in the later part of 2020s as technologies developed and scaled up.

Sustainability of the textile sector is improved with conventional textile chemicals being replaced with materials and chemicals that do not harm the environment and are nontoxic; they are safe for workers and users. Natural materials and chemicals (e.g. dyes) and utilization of side streams as source of materials from other value chains is a common practise. Synthetic biology offers new possibilities to synthetize novel fibre materials from renewable sources. Designers can easily check the sustainability of materials and chemicals using available LCA tools and versatile data sources for reviewing the impacts of the materials and substances to be selected for the product.

Longevity is also prioritized in product design; this applies to both physical features and visual appearance of the products. Collections (in fashion) and product designs change slowly compared to current fast fashion. Therefore, items from different seasons can be easily combined together. Modular and modifiable textiles and materials enable visual versatility. Examples include interchangeable decorations or modules and colour-changing textiles. Different textile finishes and treatments enable the extension of the lifetime and enable easy care. Advancing circular design thinking in education has boosted the transition, and textile products entering the markets comply with the above mentioned demands.

The extension of the product lifetime of new products and used products can also be achieved with easy repairability and refurbishing. The compatibility of different components and materials enable product updates. Furthermore, refinishing technologies are applied i.e. in adding functionalities that increase quality and value for the user. Smart and intelligent products that are safe and sustainable satisfy user needs and provide additional value.

Recyclability is considered in raw materials choices and in product structures when function and purpose permits to do so. This means that high quality and product properties are prioritized over easy recyclability. Monomaterials are favoured over blending when blending is not justifiable for durability or similar reasons. The modularity of products is used to make recycling easier, for example, different layers can be disassembled easily, and non-recyclable components are simple to separate. There are no longer textile materials that cannot be recycled in consumer every-day wear, in turn, in technical and high-performance textiles products exceptions are accepted.

Textile production is more sustainable and material efficient supported by digital technologies and comprehensive sustainable management of the supply chain. The production is lean, optimized and transparent, minimizing the amount of used materials and the production steps, while utilizing side streams fully. New technologies are applied for minimizing waste and environmental impact of the textile sector. Development has been especially focused on replacing the most harmful processes (and chemicals, see above) in the textile production. Online-LCA is used for monitoring the emissions of the production and for adjusting the operations and processes accordingly to avoid the exceeded emissions. Technological solutions have been developed to prevent the microplastics leakage into nature.

Textile production is returned closer to customers and to the generation locations of the secondary raw materials and the recycling facilities. The recovery of textile production based on recycled fibres has started in Finland. Transportation chains are efficient and long distances are avoided. A smaller scale sustainable local production is established and delivery is close to markets. Personalized products are produced on-demand and on-the-spot based on the customer needs. Automation helps in the production and customization of materials and products, for instance, AI assisted sewing enable adjustment in the final assembly of the garment. Avatar technology and 3D-modelling is used commonly to ensure the fit and satisfaction of the user. Advanced, zero waste 3D printing for printing the textiles from recycled and recyclable material can are used in stores and can also be acquired for home use.

Present 2021 – main challenges

Fast fashion, low cost mass production and globalized value chains are dominating the industry. Textile side stream utilization is relevantly low. Eco-design principles are not widely applied. Modularity thinking is known, but not put into implementation yet. Zero waste technologies like 3D printing and seamless knitting are in scarce use due to their limitations.

Automized sewing and other similar technologies enabling more efficient production still need more development. Technologies for body measurement systems and avatar technologies enabling customized products exist, but has not yet taken off.

How to reach the vision?

The development of new materials should include holistic design thinking including aspects such as recyclability and dyeability. Understanding of the eco-design principles needs to be spread, and care should be taken in contradicting aspects between recyclability and durability. There can be trade-offs in sustainability impacts and chosen strategies in design needs to be prioritized depending on the product type. New products need to include standardized ID that contains sufficient material and product information, while physical tag (on the product) not hindering the recyclability. For the advancement of the sustainable textile production, there is a need to facilitate investments, especially by SMEs, in piloting and early-market adoption of innovative enabling technologies and business models.

Attitudes needs to be changed within fashion houses and textile brands, since just using *only bio-based* materials is not enough. Development of certification and standardization for sustainable materials helps designers and increases public acceptance of circular materials. Certification would provide a more flexible way to do this, but if the voluntary actions do not become a common practice, standardization and regulation needs to be applied. The latter being more rigid, protectionistic option.

Better forecasting of demand and moving towards order-based production can be used to reduce material wastes. This needs to apply to the whole value chain from reduction of the lost resources during production to retail and losses caused by unsold items. In manufacturing of fabrics, especially processes such as dyeing, and printing can be done based on orders. It also applies to making of the final products.

The development of fabric lay cutting softwares, for example, with better adjustability to fabrics width can be used to reduce material wastes during production. In ultimate cases with development of avatar technology and total customization of products. This requires development of technologies enabling on-site customization and production, for instance increased use of semi-finished textile products, in which seams are left open in factory and can be finished in store according to customers measures (like current tailor-made suit).

Enablers	Barriers

• Driving eco-design principles politically: using subventions and/or taxation to support it; supporting certificates and requirement of standardization if needed.
• Promoting and advancing use of less harmful chemicals
• Using LCA and circular design as precondition for research funding
• Development of recycling processes and infrastructure for the whole value chain increases availability of recycled fibres, thus reducing costs of labour and prices of recycled materials
• Development of synthetic biology enables synthetization of cotton-like fibres from air and water and wool-like fibres from proteins
• Consumers willing to change their attitudes towards waiting time in customized products
  • Local production to speed up the delivery
  • Welcoming the waiting time since customized products are unique and made-for-you-only
• Economic gain for industry in the result of reduced material and product losses
• Promote and offer incentives for circular procurement
• Facilitating more investments
	• No sufficient market incentives for sustainable production
	• Targets set by regulation do not support holistic changes in production and consumption, rather support status quo
	• Politicians have difficulties to make an impact since they cannot necessarily see the big picture related to industry (compared to challenges in single use plastics directive, the aim was to affect the use of single use items, instead made plastics use in general more difficult)
	• Limitations of certain new technologies (like 3D production) in textile production – structural properties differ from traditional textiles effecting e.g. mechanical properties and feel
	• Consumers are used to fast deliveries, but reasonable waiting time needs to be accepted for customized and made-to-order products

8.3.3 Business Models of Textile Sector

Vision 2035

The textile sector is profitable, while seeing environmental and social responsibility as valid sign of success as economics. The amount of consumers and end users of textiles has increased, but the consumption (amount of items sold per customer) is reduced with the supply of novel and versatile textiles business models. Business is based on high-value and high-quality products, instead of large volumes of low-value textiles. Measuring the value of companies considers positive environmental actions, the promotion of circular economy and the actual price that incorporates all of the costs of the operations into price tag. From the consumption side, the increase in prices is tackled by service and sharing models enabling access to textiles also for the low income housings. Fast and low-price fashion is seen as an unsustainable option and is avoided.

Reuse business thrives enabled by materials and products that are made to last while timeless fashion has become the most preferred custom. Leasing, clothing library services, renting and product-as-a-service are common practices, and the consumption of pre-used textiles is as easily accessible as purchasing new textiles. Re-use business is more profitable for brands than fast-fashion with versatile services such as styling services that builds styles from reused items or maternity boxes that are gathered from used clothes. There is a supply with different offerings for a range of styles and needs. In addition to selling preowned textiles, consumers are also renting and leasing their own wardrobe and textiles via digital platforms and hybrid business providers, for instance, kindergartens renting most of the needed clothes. Textiles, for the most part, are delivered in reusable packaging, while delivery routes are optimised to avoid and reduce environmental impact.

Servitization is deeply incorporated into textile business. All kinds of textile products are available *as-a-service*. In addition, materials-as-a-service model has become a widespread practice in B-2-B textile business. Joint ownership of textile products is commonly accepted. Models where ownership remains within companies (e.g. leasing) enables multiple use cycles for textiles as material recirculation remains as a responsibility of a material owner enterprise.

Retails stores have re-formed their services into service hubs. in the near future, for instance, sports products, changing décor textiles, the fitting of clothes can all be accessed in the same hub. In parallel, there are on-line service players with diverse service blocks, which offer purchasing, changing, modifying different type of textiles from the same hub. Demand-driven production is local and operates for instance in stores where on-demand personized products can be ordered and produced close to customer.

The renewal of textiles, repair and refurbishing are widely available as a service. Clothing customization and repair services in shopping malls co-exist and operate similar to shoemaker stores. The competence in fixing and repair sewing of the end users is promoted via competence support services, and via repair café type of facilities where it can be done, for instance such as Verstas 247.

Present 2021 – main challenges

The quality and durability of textiles is poor. Lifetime extension, renting, recycling and re-circulation in circular economy business models is thus not feasible. In worst case, clothing is on sale only for one month. Attitudes towards the pre-owned textiles are still partly negative. Clothing stores are the largest mall tenants.

Clothing donations are rising continuously, meaning that the purchase of newly made textiles is still high and, at the same time, end users are gaining knowledge on reuse and recycling. Recycling models of the companies are used for selling point and do not necessarily contribute to sustainability; and some might be considered as green washing.

How to reach the vision?

Technical requirements for enabling reuse, repair & refurbishing business models for textiles necessitates setting criteria for quality and durability of textiles. Establishing an uniform criteria for the condition and classification of textiles assures operational precondition for companies and different actors for estimation of the economic and material value of textiles. When there is a standardised procedure for determining the lifetime goal for a specific textile product type and for how many cycles, i.e. used hours, instance of use, washing times it should last, there is an opportunity to maximize the utilization rate of textile products according to the purpose of use.

In addition, there is a need for developing solutions for efficient determining of the condition of pre-used textiles between each cycle. These solutions call for cross-sector collaborations and partnerships. For instance, determining the condition of the preowned textile product is not a trivial task. If there no standardised procedures for quality and condition determination it is done based on the subjective view of each company or actor, which can hinder the attitudes towards preowned textiles if the condition descriptions differ significantly or are variable. Currently, condition estimation is mainly done manually and there is an urgent need for developing technologies for automatized estimation of condition applying, for instance history data, machine learning and AI.

For the implementation of these novel service-based textile business models, there is a need for an adaptation of digital technologies, development of digital platforms, especially compatibility of different platforms and technical possibility for exchange of information between platforms. These service-based models call for a diverse understanding of the product’s lifecycle data and providing needed solutions based on the analysis of the data. Purchasing a preowned textile differs in many ways from purchasing a new item with attributes such as the size, colour, shape, fit, material conditions and their availability cannot always be assured.

Novel businesses should concentrate on services and solutions that make the process of finding desired textile easy, such as development tools for automized size measuring for pre-used textiles and integration of size data of consumers to assist in finding the fitting products. Moreover, building services around this solution to provide a recommendation for fit textiles services, which would give suggestions to customers on what would suit them based on measurements of the product data and customer size. Many of the operating retail stores do not provide these types of solutions as a service, yet.

For now, second-hand store is not necessarily the most viable option for purchasing a specific textile item in search. This does call for viewpoint changes from the end users' side, but despite this the purchase should be made as easy and convenient as possible to a buyer. In this, the adaptation of digital technologies plays a vital role. In addition, price setting is an essential part in service-based businesses and how the service is received. If the concept of a business is made easy for the customer, then perhaps customer might be willing to pay for the ease that the service provides.

Bringing novel service-based solutions to markets call for re-arrangements of the roles of different actors and on how the supply chains have been organized. Taking new roles can open new revenues for the traditional actors in the transition towards circular business models. In the future, retail stores will need to diversify their services instead of straightforward linear sale by providing services such as leasing, fitting, repair and for some items also on-demand production. For instance, companies could provide renewal services for textiles in the form of dyeing and digital printing.

R&D plays an integral role in fostering the circular transition. Integration is identified as one of the key aspects in the R&D for achieving successful results; and bringing the needed technologies and solutions to the market. Especially, one of the recognized aspects is putting emphasis on appropriate financial instruments that are needed for R&D.

Enablers	Barriers
• Improving circular services for textiles • Getting partners for enhancing repair services, for instance, players that help in finding repair-as-a service businesses • Design and reparability of a product • Clothing repair service support for businesses (e.g. VAT reduction), for consumers e.g. household deduction • Necessary training related to the services required around the products, e.g. for maintenance • Second-hand web search engines efficient in search of size, model, colour and other related features of textiles • Designing textiles for circularity • Sustainable purpose driven production and use of clothes • Efficient collection and sorting of textiles • Production of high quality textiles that enable reuse, repair, renting, leasing and recycling • Increase in awareness about the price level of clothing and the requirements for quality (durability) • Risen price awareness. Consumers are willing for paying for mending and modifying services	• Lack of repair service supply • Not enough specialists for fixing sewing machines. In general lack of competence in fixing and repair • Negative attitudes towards re-used textiles • Low quality of re-used textiles • Manual inspection increases the price of re-used textiles, thus the price and the condition of the product do not match, especially for cheap products. The price may match if product's original price included the actual cost of production • Geographically not all regions are yet willing to change attitudes and to accept the re-circulation and leasing of clothes • It is harder to ensure funding for the development of business models than for the development of technology

• Rising demand for servitization supply • Profitable prices for companies via service models • Benchmark cases and success of competitors as a motivator • Support from society and research for safe experiments of novel textile business models • Automatized services for checking and verifying the quality and condition of textiles. • Subcontractors providing services for quality and condition checking • Minimalism as ideology – capability for evaluating the true need of required textile items, thus decreasing the total amount of owned textiles.	• Difficulties to obtain funding • Local funding agencies demand for internationalization of businesses and large size of operations, while service providers are small, and their core operation is local • Micro-employment is at municipal and regional level - financial instruments are often national which do not fall within the remit of any ministry while (ERDF) is applicable to regions.

8.3.4 Technologies related to Sorting and Recycling

Vision 2035

Sorting technologies have developed to serve the sorting of reusable items as well as to produce (sufficiently) large volumes of different fractions for recycling. There are several economically feasible recycling technologies enabling textile to textile recycling, and closed loop recycling concepts have become common. Based on the quality and classification of textile waste streams, they can be forwarded into recycling process, which is optimal also from a sustainability point of view. Recycled fibres are suitable for many processes and applications without compromising the quality, while in practice future textiles with a high-recycled fibre content having a significantly higher average quality than current fast fashion items.

Textile sorting is mainly automated and moved from material identification to product-specific identification. In addition to the NIR sensor, other detection sensors are used, which enable more accurate sorting of the materials and, for example, the identification of colour and texture that were are expected to be taken into use in the early 2020’s. Artificial intelligence in identification is advanced in a way that it is possible to sort desired brands and vintage products automatically for reuse, also enabling the automatization of pricing. With these technologies, a reuse actor can determine the needed specifications for recirculation beforehand - such possibilities are expected to be available in latter part in the latter part of the 2020’s.

Sorting for recycling is easy since new textiles have a built-in ID that can be read for instance, within collection container or during sorting. The ID identifies the product and may also include information of the recycling routes determined during the product’s design stage. Since there are no longer non-recyclable materials in consumer products, product design enables easy disassembly (see Chapter 8.3.2). Furthermore, multilayer-structures do not require manual sorting anymore. Items containing hard parts can also be easily identified in the automated system and the removal of these parts is automated.

Mechanical i.e. fibre level recycling is commonly used in textile-to-textile recycling from both pre- and post-consumer streams. The understanding of mechanical opening technology and fibre qualities achievable from post-consumer waste has grown in Finland in the early 2020’s. Multiple cycles are also enabled since an automated, on-line fibre quality measurement system can be used for the optimization of yarn and fabric properties. Mechanical technology is competitive and the production of mechanically recycled fibres is a profitable business in Finland. These fibres are used for making new textile products domestically and in neighbouring countries in the latter part of the 2020’s. Due to the development of cleaning processes the use of recycled fibres are also accepted, for instance for healthcare applications and hygiene products.

Methods enabling the restoration of fibre properties, i.e. thermoplastic and chemical methods, have also evolved into a final cycle method. Companies having thermoplastic recycling technologies operate in

Finland, for instance for melt processing into composites in the early 2020's. Fibre producers can also be found in the region. In addition, chemical recycling has become more common. Especially, the recycling of cotton has increased in capacity in the latter part of the 2020's. Chemical methods are also available for fibre blends i.e. to separate materials from each other and utilizing more than one component.

Technology development and scale up has enabled textile-to-textile recycling of up to 75 % of textile materials used in consumer textile waste. Additional technologies enable an even higher utilization rate of recycled materials, and materials can also be fed into other cycles (e.g. cooperation with plastic cycles) and vice versa. Moreover, textile fibres are also made from other than textile based waste streams.

Present 2021 – main challenges

Sorting is done manually and the level of automation of sorting plants is limited to the use of conveyors. NIR is main the technology for material identification regardless of its limitations (e.g. Cura *et al.*, 2021). There is no classification system for quality determination. Reusable products are separated manually into different quality categories – low quality reusable items are exported into third world countries.

Mechanical recycling exists mainly for pre-consumer materials and its focus on down-cycling into nonwovens. In textile to textile recycling mechanically recycled fibres need to be blended with virgin fibres in order to ensure quality

Dominant recycled fibre is produced from PET bottles. Technologies enabling fibre quality restoration in textile recycling are only scarcely available. Chemical recycling methods are still in the development stage and require up-scaling. The thermoplastic recycling for synthetics are only available for certain polymers and textile waste streams

How to reach the vision?

Sorting concept development, both sensors and equipment, is a necessity for the efficient and viable recycling of textile materials. To overcome shortcomings of NIR technology and elimination of the need for a manual pre-sorting, a combination of different sensors and data processing is needed. The inclusion of artificial intelligence and learning algorithms, as well as readers of product IDs (see Chapter 8.3.2), would enable better recognition of fibre and fabric types, but also enable an application of automated sorting for re-usable items as well. Furthermore, development should be done in co-operation with machine builders in order to increase the level of automatization in textile sorting for both re-use and recycling purposes.

Pre-processing for recycling needs to be addressed as well. New methods for the automatic removal of hard parts and IDs needs to be developed and possibly combine these solutions with sorting. Similarly, we need to have the means and tools to determine the fibre quality and suitability of materials into different recycling methods. Firstly, a fibre quality based classification system needs to be developed and, secondly, a simple system to determine the fibre class needs to be built. The latter one can be partly based on on-line measurement systems, but the inclusion of materials and products information would give a better outcome and enable an automated system for classification purposes, especially for post-consumer textiles, which are typically very heterogeneous.

Recycling technologies also call for development. In the case of mechanical opening we need to build a better understanding on how to optimize the process and properties of outcome fibre materials. Specifically, how to balance between fibre lengths versus the remains of textile structures in recycled materials. The development of chemical and thermoplastic processes are as critical as well, since only via these processes the restoration of fibre properties is possible. We know that fibre blends are in many cases a more durable option compared to natural fibres alone, enabling an extension of a textile's product lifetime. Therefore, there is a need to develop fractionation processes capable of the separation of different raw materials from fibre blends in a way that we will be able to utilize all main different fractions as secondary raw materials. Techno-economically viable processes needs to be scaled up, and new actors are expected to enter the ecosystem, for example, for commercializing recycling processes and making end products from recycled textiles.

Enablers	Barriers
• The EU targets for recycling rates will force governments to also support technology development • High price and limited availability of primary/virgin raw materials (especially cotton) also increases the price of secondary raw materials, sufficient price makes processes more viable. • Increased demand of recycled and bio-based fibres. In Finland and other Nordic countries, for example, research activities have increased awareness and, thus, increased interest of the textile sector to new cellulose based, as well as recycled fibres. • Additional effect of corona pandemic has also increased interest towards locally produced fibres and self-sufficiency in fibre production	• The textile sector is not seen as a big business and therefore technology developers do not take it seriously even though the volumes of textile waste are actually huge • Economic viability of textile recycling processes is ambiguous – the prevalent situation and current investment aid conditions do not promote risky investments and the development of new processes and technologies.

8.3.5 Information

Vision 2035

Every (new and cycling) product includes sufficient & verifiable data along the entire lifecycle - before and after it, covering the in-between data of the new cycles. Retrieving and sharing data is a common practice and important part of business guiding sustainable handling and circulation of textiles. Comprehensive data availability and accessibility is enabled by reliable long-lasting technologies. All stakeholders are able to supplement the data. Extensive market data over the whole lifecycle, including history data, is available. Data related to the use phase of products is available; consumers share the information related to use and changes in the product. A certain type of information, such as chemical the content and origin of materials, is gained free and getting information is not tied up to buying the product.

Information is transparent and acts as a building block of trust in established data sharing alliances among businesses. The status of business secrets has been redefined towards more openness. The data is open for those who need it in different languages and cultures. Former competitors are regarded rather as partners in information sharing and consumers get information openly. Sharing sufficient information openly has been obligated by legislation – especially for safety and responsibility related information.

Traceability of the product covers verifiable data along the whole lifetime of the product - before and after it, i.e. between moving from one cycle into another. Tracing concerning responsibility and chemicals is especially comprehensive and reliable. Product developers get comprehensive and reliable information about use, conditions of use, user experiences and implications of use over the whole lifetime. All stakeholders agree to trace the textiles, have tools for it and are committed to tracing. Tracing directs the sustainable and legal circulation of products. The means for ensuring Information security and privacy are defined and implemented.

Present 2021 – main challenges
Availability of data is very limited, especially for reusers, circulators and recyclers. The only commonly available information is related to material information and the care instructions. There are no obligations to share information except for the material and care information, when new products are sold to customers. A lack of product information is hindering the upgrading of products. No standards for the presentation of information is causing difficulties to compare, for instance, the sustainability of textiles. There are Track&trace applications available but they are expensive and

laborious to use. Especially, the exact information about the origin of the fibres is troublesome to acquire. Material may be identified from the product by NIR or manually by an expert to some extent. There is no tracking of reuse or recycling, the information is available only about the main streams that are collected. There are limits on how to influence the consumer behaviour on returns of the textiles at their end-of-life, for instance, to certain in demand locations.

How to reach the vision?

Optimized circular textile systems require a technological system for storing data and adding types of ID into materials & fibres in a way that will not get lost at any stage of lifecycle; and which in addition does not affect the usability nor recyclability of products. Technologies for tagging products and systems managing product information are available (see Chapter 7.3). However, the recyclability viewpoint of tagging as well as building consistent and functional overall model and system for collecting and sharing data still requires improvements.

The product lifecycle data is crucial for determining the value of a product based on information gained on its properties and attributes. The relevant data for circular economy include, for example, the evidence about the positive impact on sustainability, up-to-date quality and safety information, exact materials and chemicals information, product history, and user experiences. A lack of data is impeding not only the true economic value of a product but also profitability for businesses. Product information is essential for emerging novel service-based textile business models, which are competing in the market with the new textile products. For the management of the product data, there should be a direct connection between the product and the product information. From the information user point of view, the linkage should be as direct as possible. Hence, there is a need to define between different stakeholders of the textile value chains on how these links could and should be created and managed.

Acquiring the needed data calls for the agreements between stakeholders about the openness of the data; and what data could and should be shared and with which parties (see Chapter 7.4). Currently, technologies for open data sharing for all stakeholders is available – including sharing between different platforms but their potential still remains untapped. On the other hand, improving the competence and technology for textile data management in underdeveloped producer countries of textiles which, in turn leaves few or no opportunities to affect the customs.

Furthermore, product data is needed for the environmental and social assessments of products that require from cradle-to-cradle data for making accurate calculations. Product certifications also require deep dive into material and product data covering the entire supply chain. Data gained through traceability gives means to admit for instance, certificates based on real-time data to certain batch, based on the material origin or place of production. Open sharing of information about product's lifecycle can promote the awareness of consumers about products. For instance, sustainability information can lead to increase in conscious decision-making.

Secure and trustworthy data acts as a cornerstone for reliable business (see Chapter 7.5). Therefore, the developing and adaptation of technologies enabling verification, secure storage and retrieval of data is in the centre of building circular textile networks. Security protocol is one of the aspects that needs commonly accepted guidance and regulation, which are recognized as a priority related to data of the circular transition. For instance, in reuse business model, there is a need for verification of information related to the original quality of a product (e.g. materials or the brand authentication) and its prevailing condition to formulate an accurate product ID and to estimate a fair price for a product. There are also other identified technical, technological, and behavioural challenges calling for solutions (see examples in Figure 71).

Data from value chain

- What data is available?
- How to determine to whom data is produced?
- How to determine who can access the data related to textiles?

Data from consumers

- How to collect data related to experience of consuming perused textiles?
- How to enable adding product data (to product ID's or product passports) by consumers/end users?
- Who should in this case act as a data verifier or decliner?
- How to block trolls for ensuring factual data?

Data related to maintenance

- Can washing times of textiles be traced according to washing machine's washing loads and times?
- Would it be technically possible for each textile item?
- How would consumers react to collection of such a data from households?

Data related to condition of textiles

- Can washing machine data generate information related to the condition and repair needs for textiles?
- Can tags used in textiles help both, in determining the possible washing time and the washing machine in selecting the necessary program for wash?

Data related to reuse and recycling

- How to make product passports or ID for textiles that are already in use, and are most likely linearly produced?
- Can textile tags help in determining the condition and value of textiles based on wash history with known attributes such as materials, hard parts and other properties by linking and connecting this information for estimation how much lifetime the textile has left?

Figure 71 Textile data related challenging questions calling for new technologies and solutions

The textile industry would benefit from commonly accepted, standardized form for data that determines tracking and traceability aspects. To some extent, these uniformed policies could be qualified through regulation. Standardization is especially needed for product information content, requiring also more specific information about materials – above all, for materials and chemicals that cause problems in recycling.

Enablers	Barriers
• The perceived benefit of the information obtained leads to a more open information sharing / willingness to share information • Service providers to become responsible for information management • Seeing the value of data utilization via traceability/ getting value from data sharing (traceability) • Taking data systems into use through which traceability can be managed as one aspect in textile management	• Most products in the market do not have product ID • Lack of product data hinders the reuse and recycling of the product • Information management costs are high for businesses, especially for SME's and there are limited opportunities to both invest and subcontract services and technologies related to data management • Big actors are slower and more reluctant to adopt new practices • Product ID tags do not stay on or in turn they are too hard to remove and thus hinder the recycling • Competitive position – open product data opens supply routes and insights of the business

The Telaketju vision and roadmap was envisioned together with Telaketju experts, researchers and company representatives. The core vision was formulated based on discussions and group assignments in two workshops 1) Envisioning the vision for circular textile economy and 2) How to reach the vision? Collected data from these workshops was analysed, written into a roadmap format and sent for a first feedback round. After the commenting period the text was revised in accordance to feedback and sent for a second revision, then finalized.

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Annex Dissemination Activities

The Telaketju consortium was actively communicating the project, textile recycling, circular economy and, of course, the project results. The Telaketju website (https://www.telaketju.fi/) and the Facebook pages (https://www.facebook.com/poistotekstiili/) were built for communication and to publish results of the project.

Summary of the amount of different types on publications and comparison with targets are given in Table 18.

Table 18 The targeted and realized amounts of different types of publications

Publication categories	Realized (at least)	Target (if any)
Own communication of partners and funding organizations (media releases, newsletters etc., events)	23	14
Presentations about and/or including Telaketju in national seminars, workshops etc. events	30	-
Other national events where Telaketju is somehow present	16	--
National publications including articles, blogs, webinars altogether including webinars and videos	79	15
International events (conferences, seminars, workshops) altogether including scientific publications	31	10
Media hits (in Finnish media)	118	-
Social media followers	3407	3800
Telaketju webpage visits	39084	25000

Dissemination for Finnish Audience

A wide range of themes were discussed in the webinar series which were held for the whole duration of the Telaketju 2 BF project. The webinar topics are listed in Table 19. The recordings and presentation materials, including the contact information of the presenters, are available in Finnish on the project´s website.

Table 19 Topics and summaries of Telaketju webinars (in Finnish) held during the Telaketju project

Date and presenters	Title and link
28.11.2019 Tiina Pajula, VTT	Ympäristöjalanjäljet - Miksi niitä lasketaan ja miten? https://telaketju.turkuamk.fi/webinaarit/ymparistojalanjaljet/
30.1.2020 Jouko Heikkilä, VTT	Tekstiilitieto kiertämään - tuotetiedon rooli tekstiilien kiertotaloudessa https://telaketju.turkuamk.fi/webinaarit/tuotetieto-tekstiilien-kiertotaloudessa/
27.2.2020 Saija Vatanen, VTT	Kädenjälki – Viesti ympäristöasioista positiivisesti https://telaketju.turkuamk.fi/webinaarit/kadenjalki-viesti-ymparistoasioista-positiivisesti/
11.3.2020 Pirjo Heikkilä, VTT	Johdatus tekstiilien kiertotalouteen https://telaketju.turkuamk.fi/webinaarit/johdatus-tekstiilien-kiertotalouteen/
26.3.2020 Sini Ilmonen, LSJH	Poistotekstiilin valtakunnallinen keräys kunnallisen jätehuollon toimesta https://telaketju.turkuamk.fi/webinaarit/poistotekstiilin-valtakunnallinen-kerays-kunnallisen-jatehuollon-toimesta/

30.4.2020 Eeva Pohls, Tampereen yliopisto	Tekstiilien kiertotalouden ekosysteemi: Kansallisen tekstiilikierron ajurit ja esteet https://telaketju.turkuamk.fi/webinaarit/tekstiilien-kiertotalouden-ekosysteemi-kansallisen-tekstiilikierron-ajurit-ja-esteet/
28.5.2020 Maija Lumme, Eettisen kaupan puolesta ry	Mistä tietää onko yritys oikeasti vastuullinen? - Ilmasto-, ympäristö- ja ihmisoikeusvaikutusten arvioiminen https://telaketju.turkuamk.fi/webinaarit/mista-tietaa-onko-yritys-vastuullinen/
20.5.2020 Kirsi Niinimäki, Aalto; Helena Dahlbo, SYKE; Riikka Räisänen, Helsingin yliopisto; Heli Antila, Fortum; Marjo Keskitalo, LUKE; Satumaija Mäki, STJM ry	BioColour & FINIX: Hiilineutraali tekstiiliteollisuus – tulevaisuutta vai utopiaa? https://telaketju.turkuamk.fi/webinaarit/biocolour-finix-hiilineutraali-tekstiiliteollisuus-tulevaisuutta-vai-utopiaa/
17.6.2020, Kaisa Vehmas, VTT	Miten kuluttajat suhtautuvat tekstiilien liiketoimintamalleihin? https://telaketju.turkuamk.fi/webinaarit/kuluttajien-suhtautuminen/
27.8.2020 Annariina Ruokamo, LAB	Kiertotalous tuotesuunnittelun näkökulmasta https://telaketju.turkuamk.fi/webinaarit/kiertotalous-tuotesuunnittelun-nakokulmasta/
24.9.2020 Taina Kamppuri, VTT	Sertifikaatit kierrätysmateriaalisisällön verifioimiseen https://telaketju.turkuamk.fi/webinaarit/sertifikaatit-kierratysmateriaalisisallon-verifioimiseen/
29.10.2020 Enni Arvez, LAB	Tekstiilit mikromuovin lähteenä https://telaketju.turkuamk.fi/webinaarit/tekstiilit-mikromuovien-lahteen/
26.11.2020 Hanna Lusila, Weecos	Vaikuttaminen ja vastuullisuudesta viestiminen sosiaalisessa mediassa https://telaketju.turkuamk.fi/webinaarit/vaikuttaminen-ja-vastuullisuudesta-viestiminen-sosiaalisessa-mediassa/
17.12.2020 Kaisa Ahonen, Minna Ainonen, Aleksi Leppänen & Elina Lundén, Turku UAS; Enni Arvez & Sofia Malin, LAB	Kokemuksia elinkaariarvioinnin työkaluista tekstiilialan näkökulmasta https://telaketju.turkuamk.fi/webinaarit/kokemuksia-elinkaariarvioinnin-tyokaluista-tekstiilialan-nakokulmasta/
28.1.2021 Maria Antikainen, VTT	Vaatteet palveluna – minkälaista arvoa sillä voidaan luoda kuluttajille ja kiertotaloudelle? https://telaketju.turkuamk.fi/webinaarit/vaatteet-palveluna-arvoa-kuluttajille-ja-kiertotaloudelle/
25.2.2021 Oskari Pokela, LSJH	Kuinka poistotekstiilin erilliskeräys ja lajittelu toteutetaan alueellisesti? https://telaketju.turkuamk.fi/webinaarit/kuinka-poistotekstiilin-erilliskerays-ja-lajittelu-toteutetaan-alueellisesti/
25.3.2021 Rosa Palmgren, VTT	Mallinnuksen avulla kohti kustannustehokasta tekstiilikierrätystä https://telaketju.turkuamk.fi/webinaarit/kustannustehokas-tekstiilikierratys/

A large number of blogs were written and published in Telaketju and other webpages. Many of those belong to the *Did you know that* social media campaign. List of blogs can be found in Table 20.

Table 20 Topics and summaries of blogs and News (in Finnish) published in our webpages

Date and author(s)	Title and link
3.9.2019 Marketta Virta & Jemina Hongell, Turku UAS	Festareilla pohdittiin kulutustottumuksia https://telaketju.turkuamk.fi/blogi/festareilla-pohdittiin-kulutustottumuksia/
16.9.2019 LSJH (tiedote)	Uusi teknologia mahdollistaa tekstiilien luotettavan tunnistuksen https://telaketju.turkuamk.fi/uutiset/uusi-teknologia-mahdollistaa-tekstiilien-luotettavan-tunnistuksen/
3.10.2019 Pure Waste (tiedote)	Kuluttajien pois heittämät tekstiilit päätyivät vaatteiksi

	https://telaketju.turkuamk.fi/uutiset/kuluttajien-pois-heittamat-tekstiilit-paatyivat-vaatteiksi/
6.11.2019 Sanna Virta, Painovoima ry	Paperijätteestä tekstiilijätteen uusi tulevaisuus https://telaketju.turkuamk.fi/blogi-fi/paperista-tekstiilijatteen-uusi-tulevaisuus/
11.11.2019 Suvi Järvi, Sideflow Oy	Tekstiiliteollisuuden kiertotalouden puuttuva palanen? https://telaketju.turkuamk.fi/blogi/tekstiiliteollisuuden-kiertotalouden-puuttuva-palanen/
1.12.2019 Aleksi Leppänen & Minna Ainonen, Turku UAS	Tekstiilien kiertotalous on uusi musta https://telaketju.turkuamk.fi/blogi/tekstiilien-kiertotalous-on-uusi-musta/
5.12.2019 Kati Levola, Aijuu	Mikseivät ne tee mitään? https://telaketju.turkuamk.fi/blogi/mikseivat-ne-tee-mitaan/
16.12.2019 Mika Laine, Rauman seudun jätehuoltolaitos	Poistotekstiilin keräilystä Raumalla https://telaketju.turkuamk.fi/blogi/poistotekstiilin-kerailysta-raumalla/
17.12.2019 Maarit Kiviranta, HSY	Poistotekstiilien keräyskokeilu alkoi vauhdikkaasti pääkaupunkiseudulla https://telaketju.turkuamk.fi/blogi/poistotekstiilien-kerayskokeilu-alkoi-vauhdikkaasti-paakaupunkiseudulla/
18.12.2019 Tuomas Alijoki, LSJH	Uudella teknologialla laadukasta poistotekstiilien lajittelua ja jalostusta https://telaketju.turkuamk.fi/blogi/uudella-teknologialla-laadukasta-lajittelua-ja-jalostusta/
19.12.2019 Telaketju	Tekstiilien kestävän kierron solmuja avataan yhteistyöllä Telaketju 2 -hankkeessa https://telaketju.turkuamk.fi/uutiset/tekstiilien-kestavan-kierron-solmuja-avataan-yhteistyolla/
15.1.2020 Inka Mäkiö & Henna Knuutila, Turku UAS; Eetta Saarimäki, VTT	Verkoston kuulumisia: Kohti kokeiluja ja testauksia! https://telaketju.turkuamk.fi/blogi/verkoston-kuulumisia-kohti-kokeiluja-ja-testauksia/
3.2.2020 Inka Mäkiö, Turku UAS	Verkoston kuulumisia: Vastuullisuus lähtökohtana https://telaketju.turkuamk.fi/blogi-fi/verkoston-kuulumisia-vastuullisuus-lahtokohtana/
2.3.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Rikkinäinen vaate – jätettä vai raaka-ainetta? https://telaketju.turkuamk.fi/tietoiskut/rikkinainen-vaate-jatetta-vai-raaka-ainetta/
6.3. 2020 Telaketju	Kotitalouksien poistotekstiilinkeräys laajenee – myös yritysten poistotekstiileille oma laitos https://telaketju.turkuamk.fi/uutiset/kotitalouksien-poistotekstiilinkerays-laajenee-myos-yritysten-poistotekstiileille-oma-laitos/
9.3.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Määrää vai laatua vaatekaapissa? https://telaketju.turkuamk.fi/tietoiskut/maaraa-vai-laatua-vaatekaapissa/
17.3.2020 Telaketju	Infinited Fiber innosti ja inspiroi Pariisin Premiere Vision -muotimessuilla https://telaketju.turkuamk.fi/uutiset/infinited-fiber-innosti-ja-inspiroi-pariisin-premiere-vision-muotimessuilla/
19.3.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Mitä tehdä tarpeettomille tekstiileille? https://telaketju.turkuamk.fi/tietoiskut/mita-tehda-tarpeettomille-tekstiileille/
24.3.2020 Pirjo Heikkilä, VTT	Tiesitkö että: Kierrätettävyys vai pitkäikäisyys tuotesuunnittelussa? https://telaketju.turkuamk.fi/tietoiskut/kierratettavyys-vai-pitkaikaisyys-tuotesuunnittelussa/
26.3.2020 Sini Ilmonen, LSJH	Yhteiskehittämällä ei mennä siitä, mistä aita on matalin https://telaketju.turkuamk.fi/blogi/yhteiskehittamalla-ei-menna-siita-mista-aita-on-matalin/
26.3.2020 Minna Cheung, LAB	Vastuullisten materiaalien saatavuudesta

	https://telaketju.turkuamk.fi/blogi/vastuullisten-materiaalien-saatavuudesta/
26.3.2020 Tuomas Alijoki, LSJH	Uusia avauksia Yritysten poistotekstiilitreffeillä https://telaketju.turkuamk.fi/uutiset/uusia-avauksia-yritysten-poistotekstiilitreffeilla/
31.3.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Miten varmistaa uusi elämä tekstiilileille? https://telaketju.turkuamk.fi/tietoiskut/miten-varmistaa-uusi-elama-tekstiilileille/
3.4.2020 Telaketju	HSY:n keräyskokeilu toi arvokasta tietoa https://telaketju.turkuamk.fi/uutiset/hsyn-kerayskokeilu-toi-arvokasta-tietoa/
6.4.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Miten poistotekstiileitä lajitellaan? https://telaketju.turkuamk.fi/tietoiskut/miten-poistotekstiileita-lajitellaan/
14.4.2020 Jouko Heikkilä, VTT	Tiesitkö, että: Tekstiilien kierrossa tarvitaan tietoa https://telaketju.turkuamk.fi/tietoiskut/tekstiilien-kierrossa-tarvitaan-tietoa/
20.4.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Miten poistotekstiileitä tunnistetaan? https://telaketju.turkuamk.fi/tietoiskut/miten-poistotekstiileita-tunnistetaan/
21.4.2020 Minna Ainonen & Aleksi Leppänen, Turku AMK	Kuhinaa tekstiilien kiertotalouden ympärillä yritystreffeillä https://telaketju.turkuamk.fi/blogi/kuhinaa-tekstiilien-kiertotalouden-ymparilla-yritystreffeilla/
22.4.2020 Sissi Penttilä, Reima	Kiertotalous alkaa suunnittelupöydältä https://telaketju.turkuamk.fi/blogi/kiertotalous-alkaa-suunnittelupoydalta/
27.4.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Tekstiilien kierrätysmenetelmät https://telaketju.turkuamk.fi/tietoiskut/tekstiilien-kierratysmenetelmat/
6.5.2020 Kirsti Cura, LAB	Tiesitkö, että: Tekstiilien tunnistuslaitteisto REISKAtex® – Miten kaikki alkoi ja missä ollaan nyt? https://telaketju.turkuamk.fi/tietoiskut/tekstiilien-tunnistuslaitteisto-reiskatex/
19.5.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Miten tekstiilijätteestä tehdään raaka-ainetta? https://telaketju.turkuamk.fi/tietoiskut/tekstiilijatteesta-raaka-ainetta/
25.5.2020 Annariina Ruokamo, LAB	Vaatesuunnittelijoiden pöydällä ratkaistaan myös ympäristövaikutuksia https://telaketju.turkuamk.fi/uutiset-fi/vaatesuunnittelijoiden-poydalla/
26.5.2020 Ilona Engblom, Turku UAS	Tiesitkö, että: Konenäkö tekstiilien rakenteen tunnistuksessa https://telaketju.turkuamk.fi/tietoiskut/konenako-tekstiilien-rakenteen-tunnistuksessa/
29.5.2020 Elina Lundén, Turku UAS	Sata tapaa olla vastuullinen https://telaketju.turkuamk.fi/blogi/sata-tapaa-olla-vastuullinen/
1.6.2020 Pirjo Heikkilä, VTT	Tiesitkö, että: Haitalliset aineet uusissa ja kierrätetyissä tekstiileissä https://telaketju.turkuamk.fi/tietoiskut/haitalliset-aineet-tekstiileissa/
12.6.2020 Ilona Engblom & Minna Ainonen, Turku UAS	Ilmaisen palautuksen kallis hinta https://telaketju.turkuamk.fi/uutiset/ilmaisen-palautuksen-kallis-hinta/
15.6.2020 Annariina Ruokamo, LAB	Muotoiluprosessin syventäminen kiertotalouden näkökulmasta – osa 1 https://telaketju.turkuamk.fi/blogi/muotoiluprosessi-osa-1/
15.6.2020 Annariina Ruokamo, LAB	Muotoiluprosessin syventäminen kiertotalouden näkökulmasta – osa 2 https://telaketju.turkuamk.fi/blogi/muotoiluprosessi-osa-2/
7.7.2020 Henna Knuutila, Turku UAS; Maria Antikainen, VTT	Vaatetus palveluna -liiketoimintamalli tarjoaa kestävän vaihtoehdon kuluttajille https://telaketju.turkuamk.fi/blogi-fi/vaatetus-palveluna-kestava-vaihtoehto/

5.8.2020 Elina Lundén, Turku UAS	Logot uusiksi ja työvaate kiertämään https://telaketju.turkuamk.fi/blogi/logot-uusiksi-ja-tyovaate-kiertamaan/
25.8.2020 Telaketju	Poistotekstiilien jalostuslaitoksen peruskivi muurattiin – yhteistyön hedelmät alkavat kypsyä https://telaketju.turkuamk.fi/uutiset/poistotekstiilien-jalostuslaitoksen-peruskivi-muurattiin/
28.8.2020 Pirjo Heikkilä, VTT	Telaketju 2: Julkisen tutkimuksen kuulumisia https://telaketju.turkuamk.fi/uutiset/telaketju-2-julkisen-tutkimuksen-kuulumisia/
23.11.2020, Miia Jylhä, LSJH	Jätteenpoltto ei ole kirosana https://telaketju.turkuamk.fi/blogi/jatteenpoltto-ei-ole-kirosana/
23.11.2020 Oskari Pokela, LSJH	Toimiva keräysketju pitää poistotekstiilit puhtaina https://telaketju.turkuamk.fi/blogi/toimiva-keraysketju-pitaa-poistotekstiilit-puhtaina/
26.11.2020 Pirjo Heikkilä, VTT	Kuulumisia Telaketjun tutkimuksesta https://telaketju.turkuamk.fi/uutiset/kuulumisia-telaketjulta/
17.12.2020 Taina Kamppuri, VTT	Uusiutuvista materiaaleista tekstiilikuituja https://telaketju.turkuamk.fi/blogi/uusiutuvista-materiaaleista-tekstiilikuituja/
17.12.2020 Taina Kamppuri, VTT	Sertifikaatit mahdollistavat luotettavan viestinnän kierrätysmateriaalien käytöstä https://telaketju.turkuamk.fi/blogi/sertifikaatit-mahdollistavat-luotettavan-viestinnan-kierratysmateriaalien-kaytosta/
12.1.2021 LSJH	Sähköinen julkaisu kokoaa poistotekstiilin jalostuslaitoksen kehittämisen virstanpylväät ja tulevaisuudentavoitteet https://telaketju.turkuamk.fi/uutiset/sahkoinen-julkaisu-kokoaa-poistotekstiilin-jalostuslaitoksen-kehittamisen-virstanpylvaat-ja-tulevaisuudentavoitteet/
19.1.2021 Ilona Engblom, Turku UAS	Arkivaatteet lainattuina kotiin kaksi kuukautta https://telaketju.turkuamk.fi/blogi-fi/arkivaatteet-lainattuina-kotiin-kaksi-kuukautta/
2.2.2021 Pirjo Heikkilä, VTT	Telaketju 2 -projektin kuulumisia https://telaketju.turkuamk.fi/uutiset/telaketju-2-projektin-kuulumisia/
8.3.2021 Minna Ainonen, Turku UAS	Utopia ympäristöystävällisemmistä vaatepalautuksista https://telaketju.turkuamk.fi/blogi-fi/utopia-ymparistoystavallisemmista-vaatepalautuksista/
10.3.2021 Marketta Virta, Turku UAS	Puhummeko samaa kieltä? Yhteinen termistö takaa sujuvan yhteistyön ja viestinnän https://telaketju.turkuamk.fi/blogi/puhummeko-samaa-kielta/

The students that were involved in the Telaketju 2 BF project through their work are presented in Table 21.

Table 21 The theses and other student works carried out by students related to Telaketju Tekes project and its preparation

Type	Student(s) / Author(s) and organization	Title / Information / Web link
Tuotesuunnittelun päivä 5.5.2020 (Product design day)	Sini Eskelinen, Sofia Skippari & Taina Eloranta, LAB; Kaisa Ahonen, Minna Ainonen, Elina Lundén & Aleksi Leppänen, Turku UAS	Students as workshop facilitators and participants

Bachelor's thesis	Henna Ahola, LAB	Luminatic – valoa tuottavien komponenttien lisääminen vaatteeseen. http://urn.fi/URN:NBN:fi:amk-2020112323897
Bachelor's thesis 4/2021	Enni Arvez, LAB	Kierrätysmateriaalista valmistettujen kankaiden kestävyysominaisuudet. http://urn.fi/URN:NBN:fi:amk-202104296286
Internship 5-11/2020	Enni Arvez, LAB	Microplastics study, LCA survey
Internship 6-10/2020	Sofia Malin, LAB	LCA survey
Internship spring 2021	Mirka Uunimäki, LAB	Content for Tuotesuunnittelijan työkirja
Bachelor's thesis 6/2019	Niko Rintala, LAB (ex-LAMK)	NIRS Identification of black textiles: Improvements for waste textile sorting http://urn.fi/URN:NBN:fi:amk-2019062017408
Bachelor's thesis	Minna Ainonen, Turku UAS	Kiertotalouden mukaiset verkkokauppojen vaatepalautukset – Haasteet ja kehityskohteet (Clothes Returns of Online Shopping in Accordance with Circular Economy – The challenges and subjects for improvement) https://www.theseus.fi/handle/10024/463546
Social Media	Minna Ainonen, Raisa Airola & Marina Virtanen, Turku UAS	Publishing *Tiesitkö, että* bulletins in @telaketju_poistotekstiili Instagram
Social Media	Minna Ainonen, Turku UAS	Keeping Christmas calendar presenting the companies joining in Telaketju 2 in @telaketju_poistotekstiili Instagram
Project Work	Kaisa Ahonen, Minna Ainonen, Milka Keuru, Ona Vassalo, Marius Heiskanen, Aarni Karjalainen & Muska Mäki, Turku UAS	Espanjan Demo / A project work of Alakohtainen projekti -course in Turku UAS, project owner being Telaketju 2
Bachelor's thesis	Sonja Salminen, TURKU UAS	Life cycle assessment for a t-shirt made of recycled material http://urn.fi/URN:NBN:fi:amk-2021061415942
Bachelor's thesis	Aleksi Leppänen, TURKU UAS	Experiences of using environmental tools from textile industry perspective http://urn.fi/URN:NBN:fi:amk-2021062216540
Report	Elina Lundén, Kaisa Ahonen & Aleksi Leppänen, Turku UAS	Instructions of use for Telaketju's briefcase, https://telaketju.turkuamk.fi/uploads/2020/09/d70934dd-telaketju-salkku.pdf
Social Media	Minna Ainonen, Turku UAS	Presentation of Telaketju's briefcase in @telaketju_poistotekstiili Instagram
Report	Kaisa Ahonen, Minna Ainonen & Aleksi Leppänen, Turku UAS	Product as a Service review
Listing and visualization	Kaisa Ahonen & Aleksi Leppänen, Turku UAS	Listing and visualization of the business models of Finnish textile companies
Visualization	Kaisa Ahonen & Aleksi Leppänen, Turku UAS; Josefina Yrjölä, University of Lapland, trainee at Turku UAS	Visualization of the life cycle of wool products https://telaketju.turkuamk.fi/kokeilu/villatuotteen-elinkaari/
Blog	Elina Lundén, Turku UAS	Logot uusiksi ja työvaate kiertämään

		https://telaketju.turkuamk.fi/blogi/logot-uusiksi-ja-tyovaate-kiertamaan/
Blog	Elina Lundén, Turku UAS	Sata tapaa olla vastuullinen https://telaketju.turkuamk.fi/blogi/sata-tapaa-olla-vastuullinen/
Blog	Minna Ainonen & Aleksi Leppänen, Turku UAS	Kuhinaa tekstiilien kiertotalouden ympärillä yritystreffeillä https://telaketju.turkuamk.fi/blogi/kuhinaa-tekstiilien-kiertotalouden-ymparilla-yritystreffeilla/
Article	Minna Ainonen, Turku UAS	Ilmaisen palautuksen kallis hinta https://telaketju.turkuamk.fi/uutiset/ilmaisen-palautuksen-kallis-hinta/ and https://www.uusiouutiset.fi/share/8614/dbf296
Report	Raisa Airola, Turku UAS	Social Cost Benefit Analysis
Report	Kaisa Ahonen, Minna Ainonen, Elina Lundén & Aleksi Leppänen, Turku UAS; Enni Arvez & Sofia Malin, LAB	Review of LCA tools used in textile industry
Webinar	Kaisa Ahonen, Minna Ainonen, Elina Lundén & Aleksi Leppänen, Turku UAS; Enni Arvez & Sofia Malin, LAB	Kokemuksia elinkaariarvioinnin työkaluista tekstiilialan näkökulmasta https://telaketju.turkuamk.fi/webinaarit/kokemuksia-elinkaariarvioinnin-tyokaluista-tekstiilialan-nakokulmasta/
Webinar	Enni Arvez, LAB	Tekstiilit mikromuovien lähteenä https://telaketju.turkuamk.fi/webinaarit/tekstiilit-mikromuovien-lahteen/
Report	Elina Lundén, Turku UAS	Visualization of value chains in textile industry
Project	Emmi Loijas & Anne-Mari Savola, Turku UAS	Video ”Puhkirakastettu”, published in @telaketju_poistotekstiili Instagram
Report	Kaisa Ahonen & Aleksi Leppänen, Turku UAS	Clarifying the terms of circular economy in textile industry
Blog	Minna Ainonen, Turku UAS	Verkkotyöskentely ja yritysyhteistyö tuovat lisämaustetta työpajatoimintaan https://blogit.ts.fi/maailmanparantajat/verkkotyoskentely-ja-yritysyhteistyo-tuovat-lisamaustetta-tyopajatoimintaan/
Report	Kaisa Ahonen, Minna Ainonen, Aleksi Leppänen, Elina Lundén & Marina Virtanen, Turku UAS	Rank-a-brand review
Research	Elina Lundén & Marina Virtanen, Turku UAS	Research on smart clothing
Report	Elina Lundén, Marina Virtanen & Raisa Airola, Turku UAS	Review of smart clothes with a future perspective
Article	Minna Ainonen, Kaisa Ahonen & Aleksi Leppänen, Turku UAS	Environment first – Companies are interested in sustainability
Graphic design	Aleksi Leppänen, Turku UAS	Graphic design of icons for Telaketju 2
Blog	Minna Ainonen, Turku UAS	Utopia ympäristöystävällisistä vaatepalautuksista https://telaketju.turkuamk.fi/blogi-fi/utopia-ymparistoystavallisemmista-vaatepalautuksista/
Event	Leevi Ahokas, Tommi Mäkilä, Jemina Hongell,	RockSock stand in Ruisrock 2019

	Salla-Kaisa Heliander, Veera Lehmusoksa, Saara Ahtaanluoma, Leena Järveläinen, Pirkka Pajumäki, Viivi Huunonen, Karoliina Köyhäjoki, Ella Rasimus, Lassi Kujanen & Elina Toivanen, Turku UAS	https://kiertotalous2.turkuamk.fi/yleinen-fi/ylijaamatekstiilit-rokkasivat-ruisrockissa/
Event	Aleksi Leppänen, Turku UAS	Youtube playlist for Vaatevallankumous 2020 https://www.youtube.com/playlist?list=PLFdbh8fU3Amdqiw7KtfwLpMuoO39vKmhT
Workshop	Kaisa Ahonen & Elina Lundén, Turku UAS	Pure Waste's Product as a Service pilot experiment's telephone answering service
Workshop	Minna Ainonen, Turku UAS	Kotimainen työllistävä työ
Research	Elina Lundén & Marina Virtanen, Turku UAS	Collecting useful stock photos
Research	Minna Ainonen, Aleksi Leppänen & Marina Virtanen, Turku UAS	Review of Circularity ID
Translation work	Minna Ainonen, Turku UAS	Translating the Telaketju.fi website into English
Improvement work	Minna Ainonen & Kaisa Ahonen, Turku UAS	Improving the Telaketju.fi website
Workshop	Aarni Karjalainen, Turku UAS	Technical support in the worshop of Vastuullisuus-Brändäys-Viestintä (VBV)
Research	Aleksi Leppänen & Kaisa Ahonen, Turku UAS	Review of the law of corporate social responsibility
Research	Aleksi Leppänen & Kaisa Ahonen, Turku UAS	Review of STWI
Instruction manual	Antti Terho, Vilma Pulkkinen & Kaisa Ahonen, Turku UAS	Instruction manual for the NIR scanner
Listing	Raisa Airola, Kaisa Ahonen & Aleksi Leppänen, Turku UAS	Listing the events of textile industry in Finland, in which Telaketju 2 could take part
Visualization	Kaisa Ahonen, Turku UAS	Visualizing the results of the Telaketju 2 background survey with Excel graphs
Listing	Minna Ainonen & Kaisa Ahonen, Turku UAS	Doing this list for the end report of Telaketju
Blog	Aleksi Leppänen & Minna Ainonen, Turku UAS	Blog "Tekstiilien kiertotalous on uusi musta" about Textile Circular Economy networking event in Helsinki 20.11.2019 https://telaketju.turkuamk.fi/blogi/tekstiilien-kiertotalous-on-uusi-musta/
Innovation camp	30 students from different universities (Turku UAS, University of Turku, Åbo Akademi, Yrkeshögskolan Novia – Novia UAS, Humanistinen ammattikorkeakoulu, Turun ammatti-instituutti)	https://kiertotalous2.turkuamk.fi/tapahtumat/challenge/

Research project	24 Turku UAS Mechanical Engineering students	Project work on using machine vision for textile structure recognition on the Sensors and Machine Vision course, spring 2020.
Research project	Nelli Löfberg, Joona K Ikonen, LAB	Coating felted wool for better durability
Workshop	Markus Juntunen, Henna Ahola, Nelli Löfberg, Emma Valtonen, LAB	FTIR and tactile recognition demo during Kätevä & Tekevä -Fair in Lahti, autumn 2019.
Exhibition	Saana Hakosaari, Mirka Vilkman, Minna Kotiranta, Markus Juntunen, LAB	Upcycling and Zero Waste Fashion Design Exhibition during Kätevä & Tekevä -Fair in Lahti, autumn 2019.
Blog	Mirka Uunimäki LAB	Design for longevity, workwear. Published in Uusiouutiset 01/2020
Research and design project	15 students from LAB	Designing clothing for rental on the Creative Design Methods course, spring 2020.
Research and design project	30 students from LAB	Designing workwear for long use and easy recycling on the User-Centered Design course, autumn 2019 and 2020.
Visualization	Veera Konga, LAB	Visualizing the care take and handling instructions for felted wool products for rental.
Research and design project	30 students from LAB	Ethical and Environmental aspects of Textiles and Clothing, Autumn 2019 & Autumn 2020: Designing clothing for circularity (Recyclability and Disassembly)
Research and design project	15 students from LAB	Sustainable Design, Spring 2020: Designing clothing for waste minimization (Remanufacture, Upcycling, Zero Waste)
Internship	Nelli Löfberg,	Kehräämö Mustalammas, Summer 2020
Exhibition	LAB students Beda Suni and Sanni Leppäsalo	Lahden Ympäristöviikko, LAB students presented their Zero Waste and Upcycling outfits (made during Telaketju Research and Design project) on the display window of boutiques Petit St. Louise and Tiistai Shop, 14.-20.9.

International Dissemination Activities and Co-Operation

The Telaketju project networked nationally and internationally. Due to covid-19, only the first one was held as physical event, and rest were virtual events

- Telaketju Networking event 20.11.2019 (in English) https://telaketju.turkuamk.fi/seminaarimateriaalit/telaketjun-verkostoitumisseminaari-20-11-2019/
- International networking webinar series with 6 webinars 16.3.2020-22.4.2021, last of which was also our final event. Presenters and topics of five first webinars of are listed in Table 22.
- Tekstiilialan digitaaliratkaisut tulevaisuudessa 25.11.2021 (in Finnish), workshop organized in collaboration with FINIX project
- Finnish-Swedish Textile Circularity Day 14.1.2021 (in English), organized in collaboration with NordicBio project https://telaketju.turkuamk.fi/seminaarimateriaalit/finnish-swedish-textile-circularity-day-14-1-2021/
- Tekstiilien resilientit kiertotalouden liiketoimintamallit 26.1.2021 (in Finnish), organized in collaboration with FINIX project https://telaketju.turkuamk.fi/seminaarimateriaalit/tekstiilien-resilientit-kiertotalouden-liiketoimintamallit-tyopaja-26-1-2021/
- Telaketju 2 Final event, National day in Finnish 21.4.2021 https://telaketju.turkuamk.fi/seminaarimateriaalit/telaketjun-loppuseminaari-2021/
- Telaketju 2 Final event, International day in English 22.4.2021 https://telaketju.turkuamk.fi/seminaarimateriaalit/telaketju-2-final-event-2021/

Table 22 Networking webinars and presentations

Date and link to recording	Presenters and titles
16.3.2020 https://telaketju.turkuamk.fi/en/networking-webinar/first-telaketju-rd-networking-webinar-was-a-success/	• Pirjo Heikkilä, VTT: Telaketju 2 project – Business from Circular Economy of Textiles • Sini Suomalainen, Aalto University: FINIX project – Sustainable textile systems: Co-creating resource-wise business for Finland in global textile networks • Maria Ström, Wargön Innovation: NordicBio project – Circular Nordic Bio Nonwoven in MedTech Application
13.5.2020 https://telaketju.turkuamk.fi/en/networking-webinar/new-rd-webinar-recording-and-materials-now-available-2/	• Jan Mahy, Saxion UAS: TexPlus: “real life” collaboration in circular textiles – a local initiative • Natalia Papu, Circle Economy: Fibersort project • Ambjörn Lätt, IVL: Swedish Innovation Platform for Textile Sorting SIPTex • Jarkko Jussila, Coveross: COVEROSS® textile finishing & protection technology
24.9.2020 https://telaketju.turkuamk.fi/en/networking-webinar/recording-and-materials-from-our-third-rd-webinar-now-available/	• Jens Oelerich, Saxion UAS: Chemical Recycling of Cotton and Polycotton Textiles • Nin Castle, ReverseResources: ReverseResources – Platform for 360° tracking & trading of recyclable textile waste • Kerli Kant Hvass, independent consultant & David Watson, Planmiljø: Post-consumer textile circularity in the Baltic countries • Linda Hornakova, Euratex: EURATEX – The voice of the European Apparel and Textile Industry
16.11.2020 https://telaketju.turkuamk.fi/en/networking-webinar/4th-rd-webinar-materials/	• Guy Buyle & Daniel Verstraete, Centexbel: RETEX – industrial recycling of textile waste streams • Enni Karikoski, Niimaar: How can we create according to circular design principles? • Gabriella Constantinou, Lifestyle & Design Cluster: Mapping of European textile plants working with fiber-to-fiber recycling technologies • Karla Magruder, Accelerating Circularity: Accelerating Circularity Project
1.2.2021 https://telaketju.turkuamk.fi/en/networking-webinar/materials-of-the-5th-rd-webinar-have-now-been-published/	• Nikola Kiørboe, Revaluate: Separate collection of textiles in 2022 – the Danish case • Katariina Kemppainen, Metsä Group & Heli Virkki, Fortum: Expandfibre – Accelerating the development of sustainable bio-products • Linea Kjellsdotter Ivert, VTI: SATIN – Towards a sustainable circular system of textiles in the Nordic region • Carolina Faria & Matias Andrew, Vincit: Planet Centric Design toolkit
22.4.2021 https://telaketju.turkuamk.fi/seminaarimateriaalit/telaketju-2-final-event-2021/	Telaketju final event, multiple presenters from Telaketju consortium

Textile recycling and circular economy related topics were frequently raised up in different media. Often journalists and reporters also contacted members of Telaketju groups for interviews. Selected examples of our communication activities are listed in Table 23. Results and work carried out in Telaketju project has also been published in more detail and results have been (and are planned to be) published in scientific forums. The conference and seminar presentations and papers as well as the separate technical and scientific publications and reports are listed in Table 24.

Table 23 Selected examples of general communication activities of the Telaketju project given in English and/or presented in international forums

Date	Event / Media	Author/ Title / Topic / Description / Link
3.-4.6.2019	World Circular Economy Forum, Helsinki	Telaketju represented at the Finnish section by project staff, the briefcase presented. Side session 3.6.
18.-21.6.2019	European Society of Ecological Economics (ESEE) conference 2019, Turku	Turku UAS, Co-creation in the Finnish textile recycling ecosystem (20.6.)
19-20.6.2019	Avfall Norge	Ali Harlin, VTT
30.9-1.10.2019	European Days of Sustainable Circular Economy 2019, Helsinki	VTT Posters on the Circular Economy of Textiles and Telaketju
4.2.2020	Telaketju News	Ilona Engblom, Minna Ainonen &Aleksi Leppänen, Turku UAS Environments first - Companies are interested in sustainability https://telaketju.turkuamk.fi/uutiset/companies-interested-in-sustainability/
17.4.2020	Vebinar: Ringmajandus ja tekstiilid / Webinar: Circular Economy and textiles, organized by SEI Tallinn	Pirjo Heikkilä, VTT 'Telaketju 2' – Taking Finland Towards Circularity of Textiles More than 100 listeners from Estonia
17.4.2020	Vebinar: Ringmajandus ja tekstiilid / Webinar: Circular Economy and textiles, organized by SEI Tallinn	Sini Ilmonen, LSJH Practical examples from Finland – LSJH: Public waste management as a platform for circularity of textiles
25.11.2020	Circular Economy in the New Nordics	Ali Harlin, VTT Panel Discussion
24.2.2021	Textile ETP Circular Economy webinar	Pirjo Heikkilä, VTT & Sini Ilmonen, LSJH Status of Textile Recycling in Finland

Table 24 The technical and scientific publications and reports of the project

Type	Event / Media	Authors / Title / Information / Web link
11.-14.6.2019	Conference, oral presentation AUTEX2019 conference, Ghent, Belgium	Kirsti Cura & Niko Rintala, LAB Using NIR technology to identify value in waste textile streams https://ojs.ugent.be/autex/article/view/11650
1-3.7.2019	Conference, oral presentation ICNF conference, Porto	Pirjo Heikkilä, VTT & co Recycled Cotton Fibres in Technical and Clothing Applications https://cris.vtt.fi/en/activities/recycled-cotton-fibres-in-technical-and-clothing-applications
21.11.2019	Textile ETP flagship 1 symposium	Pirjo Heikkilä, VTT Presentation on the circular economy of textiles
7.-10.6.2020	Conference, presentation ISPIM Innovation Conference	Maria Antikainen, VTT Sustainable circular economy value propositions in clothing as a service -model
12/2020	Article LAB Design Annual Review	Annariina Ruokamo The designer's role in the circular economy of textiles – Design for waste minimization

		https://www.theseus.fi/bitstream/handle/10024/355273/LAB_2020_12.pdf?sequence=2&isAllowed=y
12/2020	Article LAB Design Annual Review	Minna Cheung Designing clothes for rent https://www.theseus.fi/bitstream/handle/10024/355273/LAB_2020_12.pdf?sequence=2&isAllowed=y
8.2.2021	Article Recycling Journal	Kirsti Cura & Niko Rintala, LAB; Taina Kamppuri, Eetta Saarimäki & Pirjo Heikkilä, VTT Textile Recognition and Sorting for Recycling at an Automated Line Using Near Infrared Spectroscopy https://www.mdpi.com/2313-4321/6/1/11
2021	Scientific publication plan Manuscript under preparation	Hinkka V., Aminoff A., Palmgren R., Heikkilä P., Harlin A., Investigating different approaches to the end-of-life textile supply chain — postponement or speculation?
2021	Scientific publication plan Manuscript under preparation	Minna Kulju, Kaisa Vehmas, Pirjo Heikkilä, VTT Consumers' viewpoint towards circular fashion (writing on-going)